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THE PSYCHOLOGICAL REVIEW

THE THEORY AND PRACTISE OF THE ARTIFICIAL PUPIL

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So far as the writer can ascertain the references in the literature to the theory and application of artificial pupils, although not infrequent, are quite unenlightening. Yet in all work upon the visual processes in which the amount of light energy striking the retina has to be controlled the artificial pupil would seem to be an indispensable accessory. Its value in exact studies upon visual acuity is also self-evident.

The intensity of the light which strikes the retina at any time is determined not only by the intensity and distance of the source, but also by the size of the pupil. It is useless to experiment upon the effects of lights of different objective intensities upon the retina if the reaction of the pupil to these lights is disregarded, for as soon as the objective intensity is increased the pupil contracts, and *vice versa*, so that there is a tendency for the retina to receive a constant illumination, independent of changes in the intensity and distance of the stimulus. This tendency fails to be effective only for very bright or for very dim lights, for which the pupil has attained, approximately, its minimum or maximum opening.

In addition to the compensating effect just mentioned the behavior of the natural pupil offers another difficulty to the student of retinal physiology in the continued fluctuations in opening which it exhibits even for a constant illumination. These fluctuations are periodic in character, but they follow no definite law, and the average aperture about which they

hover varies for different persons and for the same person at different times. Such variations are sufficient to render impossible accurate comparative tests of retinal sensitivity without the introduction of some further artifice.

A partial solution of the difficulty lies in temporarily disabling the pupillary reflexes by the use of such drugs as homatropin and pilocarpin. This procedure, however, is not feasible in extensive researches on account of the discomfort which it entails for the subjects. Moreover, it does not insure the same pupillary opening for different persons, or even, at different times, for the same person, so that if results are to be made comparative the size of the pupil must be measured for each series of observations.

The simplest and surest way in which to eliminate the influence of the pupil upon retinal measurements would seem to be to place in front of the natural pupil a diaphragm the aperture of which is smaller than the smallest aperture of the natural pupil, and which is concentric with the latter. It is the purpose of the present paper to discuss the theory and practice of such an "artificial pupil."

The three important problems which are involved in the use of the artificial pupil consist in the determination of the proper size of the diaphragm, of the distance from the eye at which it must be placed, and the invention of some means of insuring the coincidence of the axis passing through the center of the stimulating field and that of the diaphragm with the center of the natural pupil. The geometrical and optical conditions under which the artificial pupil must be employed make it necessary for the stimulus to be distinctly limited in angular size, and thus make impossible its application in the study of vision in the extreme periphery.

The necessary size of the aperture of the artificial pupil depends upon four variables: (1) the diameter of the surface used as a stimulus, (2) the distance of this stimulus from the eye, (3) the minimal size of the natural pupil under this sort of illumination, and (4) the distance between the artificial and natural pupils. The main condition for the successful use of the artificial pupil is that it should be so adjusted that

none of the light from the stimulus is intercepted by the iris of the eye itself.

Although the refraction which occurs as the light passes through the surface of the cornea narrows the pencil of rays, practical considerations nevertheless demand that the artificial pupil be smaller than the natural one at any time. In the ensuing discussion we shall neglect the effect of refraction at the corneal surface since the error which such neglect introduces into our calculations merely contributes to the large margin of safety which is necessary, at all events in the use of the artificial pupil. The argument becomes more rigid, and also more immediately applicable to practise, if for *o*, below, the diameter of the so-called *Eintrittspupille* is employed, in place of the actual pupillary opening, the value of *x* being taken to correspond. This means using the size and distance of the apparent pupil rather than of the actual. Practically, however, the difference between these two cases may be neglected.

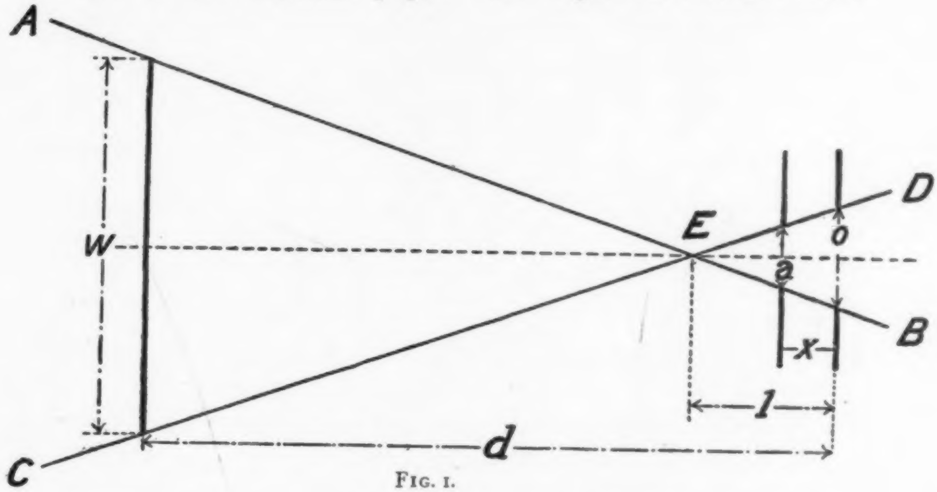

FIG. 1.

The accompanying diagram, Fig. 1, represents in cross-section the arrangement of the artificial pupil with respect to the natural pupil and the stimulating surface. *a* is the diameter of the artificial pupil, *o* that of the natural pupil, *w* that of the stimulus. *d* is the distance from the plane of

the stimulus to that of the iris, while x is the distance between the iris and the artificial pupil. The lines AB and CD represent those light rays which form the *critical* boundaries of the rays passing through the artificial pupil. (It may not be immediately obvious why these lines are the ones which it is important for us to consider, rather than the *external* boundaries of the whole pencil of rays, but a study of the diagram will make this clear.) The point of intersection, E, of the lines in question has critical significance, and may be called the *crossing-point*, the distance of this point from the plane of the natural pupil being l.

Inspection of the diagram shows the following relations to be true:

$$\frac{o}{w} = \frac{l}{d - l}, \tag{1}$$

$$\frac{o}{a} = \frac{l}{l - x}. \tag{2}$$

If we solve for l in (1), and for a in (2), and then eliminate l, we get:

$$a = \frac{o(d - x) - wx}{d}, \tag{3}$$

which gives us the maximum diameter of the artificial pupil which will satisfy the prescribed conditions.

On account of the relative convergence of the pencil of rays after it has passed through the cornea the diameter calculated by the above formula would not, strictly speaking, be the largest available opening. However, in practise it would be very unsafe to utilize an opening closer to the maximum. There are two reasons for this: first, the fact that slight accidental movements of the eye and head are unavoidable, even with the best of head-rests and fixation, and, second, the fact that the natural pupil is subject to constant fluctuations in size. Ordinarily it is advisable to work with an opening at least two millimeters smaller than the maximum for the smallest aperture of the natural pupil which is to be expected in the course of the observations.

The distance, l, of the crossing-point from the plane of the iris may be calculated from the formula:

$$l = \frac{do}{o + w}, \tag{4}$$

which follows from (1), above. The position of this point depends upon the size and distance of the stimulus and upon the aperture of the natural pupil. A knowledge of it is important, since if the artificial pupil is placed in front of the crossing-point it will necessarily fail in its purpose, no matter how small it is made. The distance of this point from the eye is, in general, of sufficient magnitude so that the artificial pupil may be placed in a position comfortable to the observer. For example, when the diameter of the stimulus is 5 centimeters, its distance 1 meter, and the natural pupil 3 millimeters, l is approximately 6 centimeters.

To determine the maximum admissible diameter of the stimulus under given conditions, the original equations may be solved for w, with the result:

$$w = \frac{d(o - a) - ox}{x}. \tag{5}$$

With, for example, a pupil aperture of 4 millimeters, an artificial pupil of 1 millimeter, and the values of x and d used in the example above, we find w to be approximately 30 centimeters. The corresponding angular aperture is 17°. It is clear that if we wish to increase the angular size of the stimulus we must decrease a or x or both. The limit for x is the distance from the iris to the cornea, *viz.*, a little under 4 millimeters, that of a is zero. Substituting these values in place of those first employed we get: w = (approximately) 1 meter. This corresponds to an angular opening of about 53°. It would appear to be the maximal size of stimulus in connection with which the artificial pupil can be used under ordinary conditions.

Evidently, however, this maximum is of such a character as to make the artificial pupil available in the study of all of the color perceptive regions of the retina, since these do not extend, in general, beyond 50°. In practise, of course, it

would be necessary for the pupil to have a finite aperture and to be removed from the cornea by a distance somewhat greater than that allowed in the above calculation (*viz.* .5 mm.).

The best possible conditions for the use of the artificial pupil would be those which go with complete mydriasis. Under these conditions the aperture of the natural pupil is about 7.5 millimeters. With an artificial pupil of 1 millimeter aperture, and a distance from the iris of 8 millimeters, the angular size of the largest available stimulus would be about 46°. The worst possible conditions are those of complete miosis, which give a natural pupil of about 1.5 millimeters. The maximum angular size of the stimulus for the latter conditions is approximately 11.5°. These maxima include the margin of safety, introduced by corneal refraction, which was mentioned at the outset. In general, of course, the artificial pupil would not be used in connection with the drugs which are customarily employed to produce mydriasis and miosis, and consequently it is necessary to base one's calculations upon the so-called physiological pupil, which lies between 3 and 4 millimeters for a considerable range of intensities of the stimulus.

The final, and perhaps the most difficult problem which must be solved in the use of the artificial pupil is that of securing what may be called *register* between the natural and the artificial diaphragms. Perfect registration may be defined as a disposition of the eye with reference to the artificial pupil such that the axis passing through the centers of the stimulus field and the artificial pupil, and perpendicular to the planes of these, also passes through the center of the natural pupil, and is perpendicular to the plane of the iris. Under these conditions the projection of the natural pupil on the plane of the artificial pupil is concentric with the latter.

The conditions accompanying the use of the artificial pupil are such as to make it difficult, if not impossible, to secure or test registration by objective observations. Approximate registration can be obtained by moving the head

slightly with the eye in position, since when the artificial and natural pupils do not coincide the intensity of the stimulus appears to be reduced. However, in most work in which the artificial pupil is helpful it is desirable that registration should be secured before the eye is exposed to the action of the stimulus.

One method of securing accurate registration would be to place two dimly illuminated diaphragms concentrically on the axis passing perpendicularly through the center of the stimulus field, these diaphragms to be at different distances from the latter and of such size that, when the eye is in position, the edge of the farther one can be seen framed in that of the nearer. If the artificial pupil now be placed concentric with the diaphragms the eye will be in register when the framing of the one diaphragm in the other appears concentric.

A neater and somewhat simpler method of insuring registration—the one now in use by the author—is the following:

It is a well-known fact that if a small source of light be held very close to the eye it will be seen not in its true form, but as a relatively large "diffusion circle,"[1] fluctuating in size with the constant changes which are occurring in the size of the pupil. Such a circle is in reality a luminous shadow of the natural pupil, and if the point of light be on the line of sight the diffusion circle which it produces will be concentric with the fovea, provided, of course, that the pupil itself is not eccentric. If, now, a true circle be placed concentric with the same axis, but at a greater distance, so that a more or less distinct image of it can be formed on the retina, this image will be seen to be concentric with the diffusion circle, but if it is displaced it will become eccentric with respect to the latter.

If an adequately small artificial pupil be placed in front of the eye and in register with the natural pupil the size of the diffusion circle will be determined by the former instead of

[1] On the theory of the "*Zerstreuungskries*," see: Helmholtz, "Handbuch der physiologischen Optik," 3d ed., 1909, Vol. 1, pp. 101–120.

the latter. With perfect registration the *Zerstreuungskreis* in question will be seen to be concentric with the image of the second circle mentioned above, but when the registration is imperfect the two will be eccentric with respect to each other. We are thus provided with a very accurate means of securing and of testing registration.

Fig. 2 represents, somewhat diagrammatically, an element of the artificial pupil apparatus which the writer has been using in his investigations concerning retinal fatigue, and

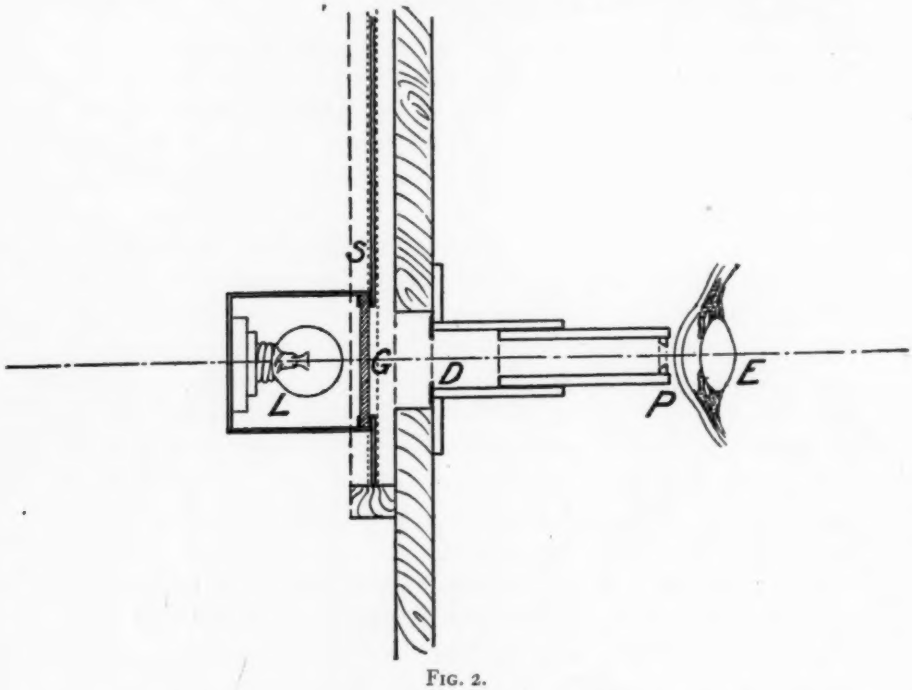

Fig. 2.

which embodies in a general way the principle just described together with the others previously discussed. The pupillary diaphragm, *P*, is held at the end of a small telescoping tube before the other end of which a small electric light, *L*, carrying in front of it a piece of opal glass, *G*, can be let down by the movement of a shutter, *S*. When this light is in position and the eye is held opposite the artificial pupil, the reflection of the light from the interior walls of the tube near to the eye

produces a large diffusion circle upon the retina. Within this circle of light is seen a smaller, dark, circular ring which is constituted by the image of the circular diaphragm, *D*, at the far end of the tube. When these two circles are seen to be concentric the line of vision must coincide with the axis of the artificial pupil and the diaphragm in question. The conditions described are those of approximate registration. In practise, registration is secured by a brief exposure of the eye of the subject to the test light—which can and should be very dim—during which exposure he adjusts his head so that the two circles are seen as concentric, fixation being directed to the center of the inner one. The head is then held firmly in position, the test lamp is extinguished, and the eye is given a period of rest sufficient to remove the effects of the faint stimulation which it has thus received. When the absence of such effects is insured the shutter is raised and the stimulus proper is exposed. When the observation is completed the shutter is again dropped, the test lamp lighted, and the state of concentricity or eccentricity of the circles is again noted. The author has found that his subjects have little difficulty in maintaining practically perfect registration in this way during periods of several minutes' duration, a simple head and chin rest being employed.

The diaphragm, *D*, acts to prevent the relatively small stimulus field from illuminating the walls of the tube, although it does not interfere with such illumination by the registration lamp. The interior of the tube should, of course, be painted black, and the current supplied to the lamp should pass through an adjustable resistance so that the intensity of the light may be easily reduced to a minimum. The apparatus as figured is not applicable to maximally large stimulus fields.

Neither of the two methods described above can be relied upon to give *perfect* registration unless a possible anatomical eccentricity of the natural pupil is taken into consideration. According to Gullstrand,[1] such eccentricity is the rule rather than the exception. Usually, however,

[1] A. Gullstrand, Appendix to Helmholtz's "Handbuch der physiologischen Optik," 3d ed., Vol. 1, 1909, pp. 270–272.

the lack of concentricity is not marked, so that if the artificial pupil employed is relatively small—say one half the diameter of the natural pupil—registration of the line of sight, which is obtained by the methods in question, may be relied upon for practical purposes.

In careful work, however, the pupils of the subjects should be measured to determine their eccentricity. Registration may then be effected by having each subject so place his eye that the inner circle is eccentric with respect to the diffusion spot in such a direction and to such a degree as to correct for the eccentricity of the pupil.

One way of testing the concentricity of the natural pupil, which will at the same time educate the subject in the amount of eccentricity necessary to correct the registration of each eye, is the following. A series of trials may be made in which the *stimulus* is viewed through the artificial pupil. Each time the head is adjusted by trial and error so that the stimulus field appears as bright as possible, a position being found which is as close as may be to the center of the range of maximum brightness, then this range has an appreciable magnitude. When this position has been secured the head is held rigidly against the head-rest and the registration lamp is dropped into place, the degree of eccentricity of the two circles being noted and recorded. The average of a number of such determinations may be used for correcting the registration.

The diffusion-circle method of securing registration permits a very simple qualitative test as to the adequacy of the register in a given instance, since the outline of this circle is determined by the effective pupil. If the registration is inadequate, fluctuations in the outline of the circle will be apparent, due to the pulsating contractions and expansions of the natural pupil. The writer has found that with an artificial pupil of two millimeters (diameter), using a small but bright stimulus in a dark room, registration of the line of sight is adequate for most subjects, although in no subjects which he has examined has such registration proven itself perfect.

THE TEMPORAL RELATIONS OF MEANING AND IMAGERY

BY THOMAS VERNER MOORE

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I. The Problem

The experiments here reported constitute a part of a more extensive study of memory and perception, which will probably be made public in the future. The work was done in the laboratory of Professor Külpe at Munich. The part now published cannot, however, be properly evaluated without some indication of the nature of the results obtained in the first section of the more extensive study. This first part consisted in an introspective investigation of the mental processes involved in perception and recall.

The material for experiment in the unpublished section consisted of spoken words, printed words, printed pictures and real objects. A series of eight words, pictures or objects were presented to the subjects. Their task was to repeat what they had seen or heard and then to give an introspective account of the mental processes they had experienced during the perception of the series and during their attempts to reproduce the same from memory.[1] The subjects were asked particularly to give an account of the temporal sequence of events as they had experienced them.

It was rather remarkable that in perceiving, the first thing in consciousness was reported as meaning the second some kind of imagery. Whereas in repeating the first thing was often an image whose meaning was understood and then designated by a word.

A few introspections will bring out more clearly what is meant by this assertion.

[1] A fuller description of the details of the technique will be given when the entire work is made public.

Perception of Printed Words

"I notice now a certain regularity in this process. With the first word, the meaning appeared with the reading, without any clear visual image of the object thereby designated. The same process takes place on the continuation of the series of words. Gradually it goes on so rapidly that during the period of exposition (2 seconds) there is time to apprehend a goodly number of apperceptive complexes, which become associated with the imaged object. The steps in the process—so far as I can notice them—are:

"1. Apprehension of the meaning.

"2. Imagery of the object—generally by means of memory images.

"3. Associations which are connected with the object."

Subject Lehner, Nov. 17.[1]

Perception of Pictures

"I look at the picture and generally have its meaning at once. Often I am not entirely certain, *e. g.*, spoon or trowel. When I have the meaning, its naming follows immediately."—Grüninger, Dec. 17.[2]

"In the perception of the several pictures, I notice that I experienced auditory-motor words in immediate connection with them, and that these words followed with varying rapidity the individual pictures. It lasted some time till I got the word 'Mitre.' In this experience it appeared to me that the rapidity with which the word comes, does not depend as much upon the finding of the words as it does upon the

[1] Ich merke jetzt eine gewisse Gesetzmässigkeit des Prozesses. Bei dem ersten Wort tritt mit dem Lesen die Bedeutung bewusst auf, ohne deutliches Gesichtsbild des darin fixierten Objektes. Derselbe Vorgang vollzieht sich bei der Fortsetzung der Reihe, allmählich mit so grosser Schnelligkeit dass während der Exponierungszeit noch Zeit bleibt eine ganze Fülle von Apperceptionsmassen bewusst zu erfassen, die sich an das vorgestellte Objekt noch knüpfen. Die Stufen so weit ich sie bemerken kann sind: 1. Erfassung der Bedeutung. 2. Vorstellung des Objektes, gewöhnlich durch Erinnerungsbilder. 3. Associationen die sich an das Objekt knüpfen. (17ten. Nov.)

[2] Ich sehe das Bild and und meistens habe ich sofort die Bedeutung. Manchmal bin ich nicht ganz sicher z. B. Löffel oder Kelle. Wenn ich die Bedeutung habe, folgt sofort die Benennung.

recognition of the picture. It is on this account that I would willingly have looked longer at the pictures. The words served as designations for the pictures or if you will the objects represented by the pictures, and had another sense, a more general meaning than their relation to the individual pictures or their objects."—Subject Külpe, Nov. 14.[1]

Repetition of Objects

"On repeating, there comes to me all of a sudden a visual image. When this image comes promptly it is usually complete. But when I must think awhile, there comes to me first of all something striking in the object. Then come further qualities, *e. g.*, to the color the form. As soon as this process of supplementing has developed to a certain point, the meaning is all of a sudden present. As soon as I have the meaning, the object seems to become still clearer. *E. g.*: All of a sudden I see the typical lustre of a pearl. Then there comes to me the round form and then all at once I know what it is."—Subject Grüninger, Dec. 10.[2]

Were meaning in some manner identical with imagery, or were it produced by imagery or the imaginal context of a sensation as Titchener suggests is often the case, we should expect just such introspections as this from our subjects—not however for memory but for perception. That they are

[1] Ich bemerke dass ich bei der Wahrnehmung der einzelnen Bilder sofort akustisch-motorische Wörter in Anschluss an sie erlebt habe, und dass diese Wörter in verschiedener Geschwindigkeit sich an die einzelnen Bilder anschlossen. Bei dem Wort Bischofsmütze, z. B., dauerte es ziemlich lang bis ich es fang. Dabei schien die Geschwindigkeit des Auftretens der Wörter nicht sowohl in der Wortfindung selbst als vielmehr in der Erkennung des Bildes begründet zu sein. Damit hängt es zusammen dass ich einige Bilder gerne länger betrachtet hätte. Die Wörter galten als die Bezeichnungen für die Bilder bzw. die Gegenstände die in ihnen dargestellt waren, und hatten einen anderen Sinn, eine allgemeinere Bedeutung als die Beziehung auf die einzelnen Bilder oder ihre Gegenstände. (14ten Nov.)

[2] Beim Hersagen taucht einfach ganz plötzlich ein optisches Bild auf. Wenn das Bild schnell auftritt, dann ist es meistens vollständig. Wenn ich einige Zeit suchen muss, dann taucht zuerst etwas besonders auffälliges am Gegenstand auf. Dann kommen weitere Qualitäten, z. B. zur Farbe die Form, und sobald diese Ergänzung einen grösseren Grad erreicht hat ist die Bedeutung auf einmal da, und sobald ich die Bedeutung habe, scheint mir der Gegenstand noch deutlicher zu werden. Z. B. Ich sehe auf einmal den eigenartigen Glanz der "Perle." Dann kommt mir die runde Form, und dann auf einmal weiss ich was es ist. (10ten Dez.)

found in memory and not in perception is strong evidence against any such theory. Here the nature of the occurrence points to the fact that an image as such means nothing just as Professor Titchener himself claims. It must be interpreted. It can be interpreted only when sufficient data is present. When this is the case, the subject *knows* what it is. This knowledge of what the image represents is not reported as a sensory element added to the elaboration of the image. A new image would itself have to be recognized. The interpretation of the image is a *knowing*. It is something which follows the awareness of the image just as understanding follows the sensations involved in perception.

Repetition of Pictures

"The repetition took place in this manner: First I thought of the first member of the series. Then without holding more strictly to the order of perception each word was spoken following an imaginal representation of the pictures. When I stopped, I attempted to bring up to myself the series. Only by the rising up of a visual image did I obtain a new word." —Subject Külpe, Nov. 14.[1]

Such introspections as these suggested a further investigation. The subjects had noticed a certain sequence of events in the process of perception. Would it be possible to react to the events that had been noted? If meaning comes before imagery in the perception of printed words, would it be possible for the subject to react, now to imagery and now to meaning? And if so, what would be the quantitative results?

In the experiments here reported this problem was attempted, to investigate, namely, by means of reaction time the temporal relations of meaning and imagery in the perception of printed words and pictures. The experiments were made in the psychological laboratory of Professor

[1] Das Hersagen geshah so dass ich mich zunächst auf das erste Glied der Reihe zurückbesann. Danach wurden die einzelnen Wörter im Anschluss an die anschaulichen Vorstellungen der Bilder ohne die Ordnung der Wahrnehmung strenger einzuhalten ganannt. Wenn ich stockte, suchte ich mir die Reihe wiederzuvergegenwärtigen und bekam erst durch eine neue Auftauchung des Vorstellungsbildes ein neues Wort (Nov. 14th).

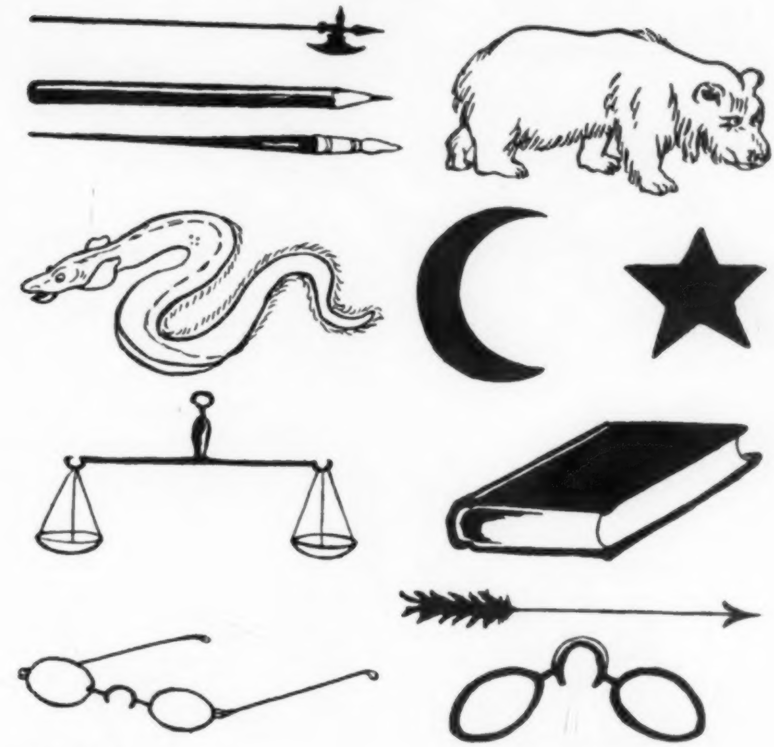
Külpe in Munich during the winter semester of 1913–14 and the summer semester of 1914. The author wishes to take this opportunity to thank Professor Külpe for his great kindness, for his interest and suggestions, and for the sacrifice of his time as subject.

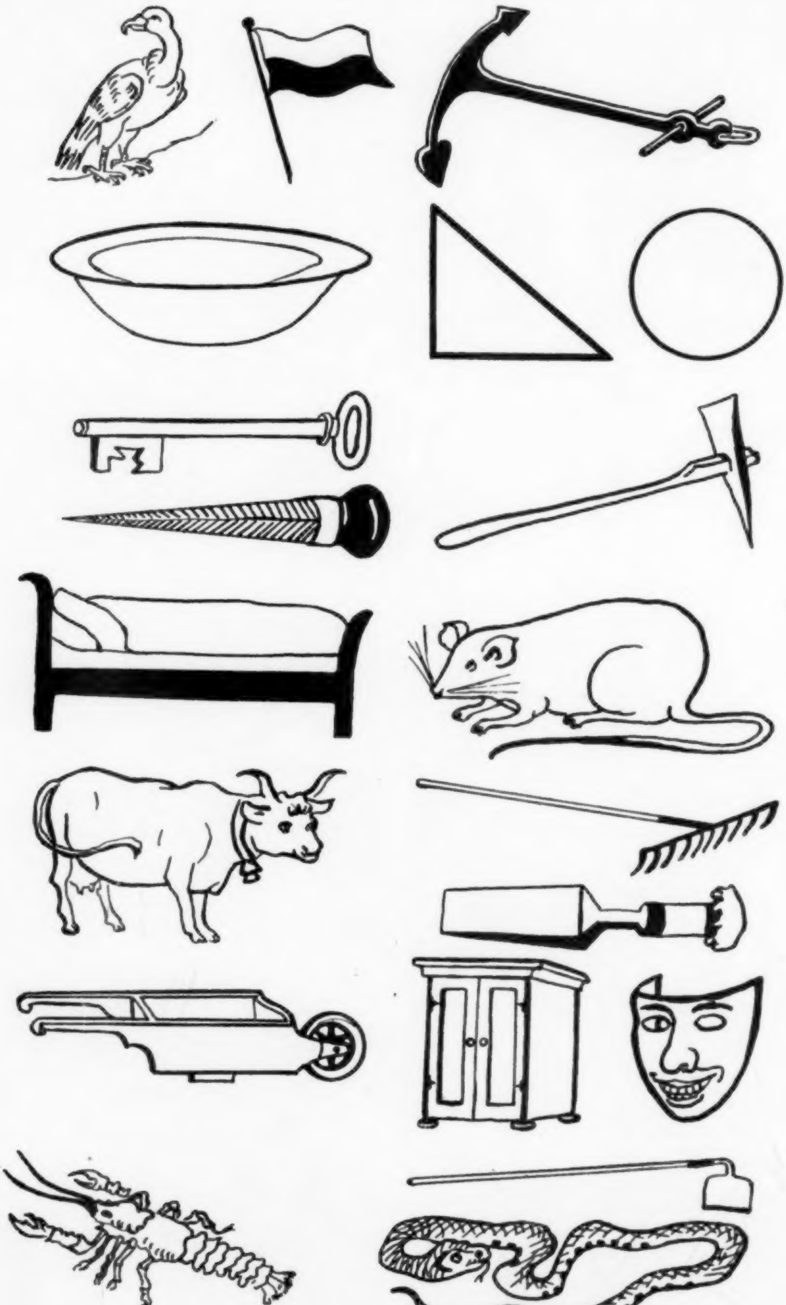
II. Method of Research

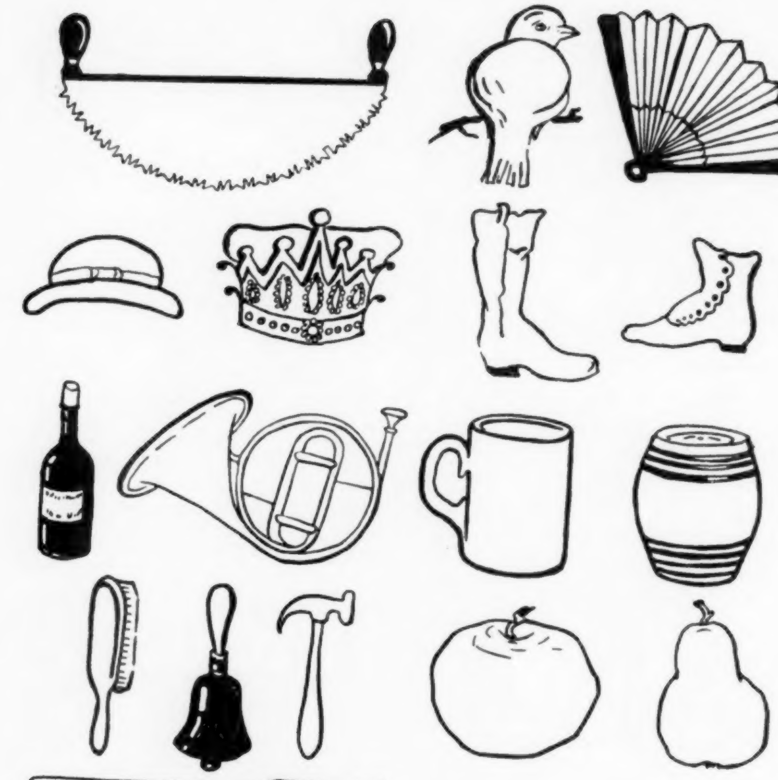
The words and pictures used in these experiments designated simple familiar objects—all capable of being visualized; *e. g.*, tree, lamp, knife. Abstract words, prepositions, etc., were not used, in order that conditions might be as favorable as possible for the development of imagery. Had such words been used the difference that was found in reaction time for meaning and imagery would have been much greater. The use of such words would indeed have been justified. For if sensations and images must explain all meanings they must be involved, and exclusively involved, not merely in the perception of things that can be immediately sensed, but also in more abstract mental content. In order, however, to test the theory on the ground where it is best able to stand, it was concluded to forego the use of any words except those that represented familiar sensory objects.

The accompanying plates give an insight into the material used in these experiments. Most of them represent objects that can be named by a one or two syllable German word. The words used were printed on cards in a large legible type.

The use of control words and drawings enabled one to be sure that the subjects were actually reacting to meanings. The controls used in the series of words were nonsense combinations of letters forming one or two syllables. The controls used in the series of pictures were meaningless drawings. In general, the subject was instructed to react (by releasing a telegraph key) in case the word or the drawing represented some real object. The words were exposed by a combination memory and tachistoscope apparatus. The reaction times were measured by a Hipp chronoscope. This was controlled by a pendulum constructed in accordance with a design by Professor Külpe. The variable error in the







chronoscope was negligible—averaging less than $3\ \sigma$. The constant error was about $70\ \sigma$. Nine subjects took part in the experiments. A preparatory signal (1–½ sec.) was given verbally with the aid of a stop watch.

III. Simple[1] Meaning and Visual Imagery

(*a*) *Quantitative Results*

The instructions to the subject in this experiment will indicate the precise nature of the problem. They are reproduced without translation. The subject read them over at the beginning of each period. A few trial periods were necessary for some subjects in order that they might learn not to react to the control word. These preparatory series were not included in the final results. One of our subjects (Gl.) never did get free from erroneous reactions and his results show a marked difference from the others.

Sie werden nach einem Signal ein Wort zu sehen (bzw.zu hören) bekommen. Ich bitte Sie zu reagieren wenn Sie das Wort verstanden oder seine Bedeutung erfasst, bzw. wenn Sie eine Gesichtsvorstellung von dem durch das Wort bezeichneten Gegenstand gehabt haben.

Die Wörte 'Bedeutung' und 'Vorstellung' werden Ihnen angeben ob das eine oder das andere verlangt wird. Nachher bitte ich mir kurz das Erlebnis zu charakterisieren, and dabei anzugeben, ob die aufgetauchte Vorstellung an die Stelle der Bedeutung gesetzt werden konnte, etwa bloss die konkrete anschauliche Erfüllung dessen war, was in der Bedeutung abstrakt intendiert wurde.

In this series, therefore, the subject reacted either (*a*) To the awareness that the word had a meaning, or (*b*) To the awareness of the visual image of the object.

If there is no difference between meaning and the visual image of an object represented by a word the average of the two series should be approximately the same. The subject ought not to be able to distinguish meaning and imagery

[1] By 'simple meaning' is not meant an absolute simplicity. The word is used to contrast this set of experiments with a later one where the more complex consciousness of purpose was required.

and this should manifest itself in averages for the two sets of reactions that approached each other within the limits of experimental error. If meaning, however, is produced by or is identical with the visual image which accrues to the sensations involved in the perception of the word, the image series should be shorter if anything than the meaning series. The results are given below. The tables are clear without any explanation, except perhaps, that in column *T* is given the

Subject Gl

Words

Date	Visual Image	*T*	*V*	Date	Simple Meaning	*T*	*V*
23/VI	Zange	1,182	628	23/VI	Rechen	368	154
	Fernglas	563	9		Besen	563	41
	Pfeil	233	321		Gabel	751	229
	Messer	639	85		Truthahn	686	164
26/VI	Lampe	640	86	26/VI	Esel	676	154
	Sichel	660	106		Trichter	550	28
7/VII	Säbel	472	82		Dreick	602	80
	Stuhl	527	27		Nest	662	140
	Eimer	429	125	7/VII	Aal	558	36
	Baum	472	82		Geige	338	184
10/VII	Trichter	346	208		Fernglas	597	75
	Korb	482	72		Besen	424	98
		12)6,645	1,831		Korb	462	60
		554	152		Maske	249	273
				10/VII	Meissel	351	171
						15)7,837	1,887
					Mean	=522	126
					Median	=563	

Reactions to visual imagery equal or below median = 8.

Subject Grüninger

Words

Date	Visual Image	*T*	*V*	Date	Simple Meaning	*T*	*V*
11/II	Auge	902	341	11/II	Schuh	682	18
	Ballon	1,092	151		Nase	787	87
	Kuh	1,660	417	16/II	Fass	661	39
16/II	Bohrer	1,277	34		Schwan	659	41
	Sofa	1,261	18		Schaf	781	81
	Stiefel	1,229	14	25/II	Ring	531	169
25/II	Schuh	1,103	140		Auge	680	20
	Fass	1,462	219		Ballon	705	5
	Nase	1,200	43		Fass	660	40
					Kuh	856	156
		9)11,186	1,377			10)7,002	656
		1,243	153		Mean	=700	65
					Median	=681	

Reactions to visual imagery equal to or below median = 0.

Subject Külpe

Words

Date	Visual Image	*T*	*V*	Date	Simple Meaning	*T*	*V*
9/II	Löwe	1,690	790	9/II	Kerze	517	14
13/II	Ballon	944	44	13/II	Schuh	538	7
	Auge	675	225		Ring	434	97
16/II	Rose	1,097	197	16/II	Nase	799	268
	Fliege	802	98		Dampsfchiff	540	9
	Veilchen	753	147		Fass	573	42
	Kuh	848	52		Ballon	708	177
23/II	Kerze	839	61	23/II	Fliege	420	111
	Schuh	897	3		Schuh	577	46
	Nase	813	87		Löwe	607	76
18/5	Ring	800	100	18/V	Veilchen	375	156
	Dampsfchiff	649	251		Rose	460	71
		12)10,807	2,055		Kuh	363	168
		900	171			13)6,911	1,242
						Mean = 531	95
						Median = 540	

Reaction to visual imagery equal to or below median = 0.

Subject Lehner

Words

Date	Visual Image	*T*	*V*	Date	Simple Meaning	*T*	*V*
16/II	Rechen	381	263	16/II	Schwan	445	24
	Buch	1,131	487		Bohrer	1,007	538
	Rettich	611	33		Sofa	663	194
	Nase	604	40		Rose	317	152
30/VI	Trichter	584	60		Brief	691	222
	Dreieck	490	154	30/VI	Palme	500	31
	Blatt	597	47		Baum	399	70
	Bär	606	38		Hirsch	389	80
	Krone	479	165		Spaten	406	63
	Veilchen	488	156		Aal	407	62
	Treppe	631	13		Krug	395	74
	Ofen	572	72		Tasse	489	20
3/VII	Säbel	588	56		Schädel	426	43
	Geige	461	183		Ohr	435	34
	Pfeil	451	193	3/VII	Spaten	518	49
	Meissel	515	129		Hirsch	371	98
	Fernglas	874	230		Baum	483	14
	Flasche	758	114		Palme	524	55
7/VII	Krug	691	47	7/VII	Bär	368	101
	Tasse	736	92		Krone	384	85
	Schädel	918	274		Ofen	429	40
	Ohr	844	200		Veilchen	344	125
	Ballon	803	159		Treppe	398	71
		23)14,813	3,205			23)10,788	2,245
		644	139			Mean = 469	97
						Median = 429	

Reaction to visual imagery equal or below median = 1.

SUBJECT MAREZOLL

Words

Date	Visual Image	T	V	Date	Simple Meaning	T	V
11/V	Ohr	1,308	221	11/V	Käfer	841	254
	Zwicker	1,633	104		Kerze	638	051
	Eule	1,598	69		Storch	831	244
12/V	Schnecke	1,374	155	12/V	Katze	576	011
	Pfau	2,721	1,192		Kuh	822	235
	Käfer	3,868	2,339		Schlange	761	174
14/V	Maus	2,610	1,081	14/V	Löwe	774	187
	Schaf	1,309	220		Stier	458	129
	Hirsch	1,222	307		Geier	325	262
16/VI	Zirkel	1,210	319	16/VI	Ohr	508	079
	Eimer	1,021	508		Eule	398	189
	Stuhl	947	582		Schnecke	676	089
	Sichel	870	659		Schlange	582	005
19/VI	Kerze	1,187	342	19/VI	Storch	693	106
	Geier	1,367	162		Kuh	650	073
	Stier	988	541		Kerze	465	122
	Löwe	1,607	78		Katze	684	097
	Schlange	1,292	237	30/VI	Maus	456	131
	Kuh	1,571	42		Pfau	436	151
	Katze	1,146	383		Schaf	697	120
	Storch	1,258	271		Hirsch	384	203
					Zirkel	406	181
					Sichel	594	007
					Stuhl	425	162
					Eimer	557	030
		21)32,107	9,812			25)14,687	3,292
		1,529	467			Mean = 587	152
						Median = 582	

Reactions to visual imagery equal or below median = 0.

SUBJECT MOORE

Words

Date	Visual Meaning	T	V	Date	Simple Meaning	T	V
9/VI	Schuh	839	330	9/VI	Finger	516	53
	Sofa	1,685	516		Buch	337	126
	Rechen	1,112	57		Schere	444	19
	Auge	1,448	279		Bürste	572	109
	Lampe	1,145	24		Fernglas	563	100
12/VI	Dampsfchiff	857	312		Uhr	401	62
	Ochse	1,553	384	12/VI	Schuh	484	21
	Frosch	1,009	160		Tiger	758	295
	Kamm	794	375		Vogel	259	204
	Bürste	815	354		Rechen	386	77
30/VI	Pinsel	1,091	78		Fernglas	396	67
	Besen	1,108	61	14/VII	Sofa	245	218
	Handbeil	1,188	19		Kamm	572	109
	Vogel	1,155	14		Auge	583	120
	Tiger	1,275	106		Frosch	436	27
	Uhr	1,209	40		Bürste	440	23
	Schere	937	232		Dampfschiff	478	15
14/VII	Schuh	1,445	276			17)7,870	1,645
	Rechen	1,544	375			Mean = 463	96
		19)22,209	3,992			Median = 444	
		1,169	210				

Reactions to visual imagery equal or before median = 0.

SUBJECT SCHERREN

Date	Visual Image	T	V	Date	Simple Meaning	T	V
22/VI	Krebs	9,807	5,140	13/VII	Fliege	656	104
	Stern	4,537	130		Fächer	988	228
13/VII	Herz	3,370	1,297		Finger	846	86
	Trommel	6,505	1,838	21/VII	Herz	788	28
	Spinne	4,587	80		Fliege	1,034	274
	Koffer	2,531	2,136		Stern	1,080	320
20/VII	Flasche	3,159	1,488		Krebs	963	203
	Hirsch	3,411	1,256		Koffer	552	208
	Säbel	5,354	687		Spinne	697	63
	Traube	5,402	735		Trommel	561	199
	Engel	5,340	673		Säbel	631	129
	Fächer	2,007	2,660		Flasche	969	209
					Engel	378	382
					Traube	501	259
		12)56,010	18,120			14)10,644	2,692
		4,667	1,510			Mean =760 Median=742	192

Reaction to visual imagery equal or below median=0.

SUBJECT STAPPEN

Words

Date	Visual Image	T	V	Date	Simple Meaning	T	V
12/II	Ring	572	87	12/II	Veilchen	604	63
	Auge	613	46		Fass	743	202
	Ballon	584	75		Kerze	514	27
	Stiefel	656	3		Löwe	509	32
	Schaf	634	25	17 II	Rose	497	44
17/II	Rettich	1,076	417		Kuh	423	118
	Nase	565	94	19/II	Haken	573	32
	Fass	600	59		Lilie	507	34
	Rechen	657	2		Storch	511	30
	Nest	874	215		Sichel	614	73
19/II	Säge	707	48		Lampe	516	25
	Maske	632	27		Sofa	485	56
	Uhr	518	141				
	Esel	537	122				
		14)9,225	1,361			12)6,496	736
		659	97			Mean =541 Median=513	61

Reactions to visual imagery equal or below median=0.

reaction times in thousandths of a second. Under V, the variations from the mean.

At the bottom of each column the mean reaction times and mean variations have been calculated. The median for the reaction times to meaning have also been determined.

With but one exception, our nine subjects show a marked difference in their reactions to meaning and imagery. The

SUBJECT T

Words

Date	Visual Image	T	V	Date	Simple Meaning	T	V
	Kette	1,129	58		Puppe	747	255
	Nest	1,162	25		Bretzel	794	302
	Trichter	1,774	587		Mond	754	262
	Stuhl	890	297		Schädel	546	54
	Anker	1,306	119		Taube	884	362
27/VII	Ballon	1,257	70	27/VII	Zirkel	753	261
	Auge	1,216	29		Hirsch	520	28
	Apfel	905	282		Engel	569	77
	Eimer	1,295	108		Besen	499	7
	Ofen	1,109	78		Pferd	517	25
	Kuh	995	192		Hund	498	6
	Tiger	1,260	73		Geige	464	28
	Fass	1,132	55		Schiff	667	175
	Strumpf	879	308		Tiger	347	145
	Schrank	1,263	76		Schnecke	453	39
	Schlange	866	321		Pfau	554	62
	Fächer	1,259	72		Fliege	470	22
	Herz	1,845	658		Fahne	441	51
	Hahn	947	240		Finger	793	301
28/VII	Krebs	2,176	989	28/VII	Stern	369	123
	Spinne	1,516	329		Trommel	335	157
	Hase	1,072	115		Koffer	525	33
	Schlitten	906	281		Nase	527	35
	Feile	1,541	354		Schlüssel	556	64
	Hand	900	287		Hammer	479	13
	Handschuh	871	316		Spaten	411	81
	Eule	999	188		Bär	401	91
	Kirsche	921	266		Klavier	663	171
	Löwe	802	385		Kerze	419	73
	Leiter	1,415	228		Bleistift	381	111
	Fernglas	1,677	490		Nest	352	140
	Wiege	1,336	149		Wage	367	125
	Wurst	993	194		Bohrer	307	185
29/VII	Löffel	806	381	29/VII	Fliege	304	188
	Haken	2,115	928		Trommel	376	116
	Veilchen	1,315	128		Brille	362	130
	Treppe	919	268		Lilie	369	123
	Bretzel	779	408		Blatt	303	189
	Turm	894	293		Bürste	312	180
	Trichter	1,030	157		Truthahn	301	191
		40)47,472	10,782			40)19,689	4,981
		1,187	269		Mean = 492		122
					Median = 474		

Reactions to visual imagery equal or below median = 0.

one exception is not to be explained by individual difference in mental type, but rather by an anxiety to react as quickly as possible. At first he reacted to every nonsense word. He was then tried with pictures. Here again, every meaningless drawing elicited a reaction in spite of instructions. The reaction times at first varied around 100 σ. Later he was

asked to wait each time and make a judgment that he had fulfilled the task given him. Even under these instructions, he continued to react occasionally to nonsense words—the following reaction being very much retarded. He finally gave up the experiments. What would have resulted had he by practice become entirely free from erroneous reactions one cannot say. It would seem, however, more fair to a just conclusion to exclude rather than include his results in our summary. Leaving aside the results of this subject, the reaction times to visual imagery were all but one above the median of the reaction time to meaning. It is worthy of note that this single exception is the first recorded reaction of this subject. (He had made several practice series before.) Our subjects made 150 reactions in all. Were it merely a matter

SUBJECT MAREZOLL

Wörter

	Visual Image	Simple Meaning	*D*
Ohr	1,308	508	+ 800
Eule	1,598	398	+ 1,200
Schnecke	1,374	676	+ 698
Pfau	2,721	436	+ 2,285
Käfer	3,868	841	+ 3,027
Maus	2,610	456	+ 2,154
Schaf	1,309	697	+ 612
Hirsch	1,222	384	+ 838
Zirkel	1,210	406	+ 804
Eimer	1,021	557	+ 464
Stuhl	947	425	+ 522
Sichel	870	594	+ 376
Kerze	1,187	638	+ 549
Geier	1,367	325	+ 1,042
Stier	988	458	+ 530
Löwe	1,607	774	+ 933
Schlange	1,292	761	+ 531
Kuh	1,571	822	+ 759
Katze	1,146	576	+ 570
Storch	1,258	693	+ 565
	20)30,474	11,425	19,259
	1523.7	571.2	962.9

of chance that reaction times to imagery should be longer than those to meaning we could find about 75 longer and 75 shorter. As a matter of fact, we find 149 longer and only one shorter. In spite then of the rather small number of reactions (conditioned by taking the introspective reports) there is over-

whelming evidence to show that something more than chance has to do with the difference in reaction time to meaning and imagery. This difference is not due to the words used for imagery and meaning. Not only were the words in both cases representative of sensory objects but care was taken to repeat the same words in the two series. A table is given above comparing the reactions of one subject for meaning and imagery to the same words. Under *D* is given the difference between the two. The reaction time to imagery is always longer than to meaning. With some of our subjects the results are not so unanimous, the meaning reaction being occasionally longer. This is to be explained mainly by the effects of practice, though something is no doubt due to accidental variation.

(*b*) Introspective Data

From the quantitative results that have just been given, it is evident that the subjects give a different response when told to react to meaning or imagery. Were we to stop with the quantitative results we would not know very much about the nature of that difference. Is meaning simply an early stage in the development of the image? Is it a vague confused image? Is it merely the realization of the power to visualize the object? Is it the tendency of a number of images to crowd into consciousness? What is the difference? There can be no doubt that a considerable difference exists and it is of great importance to find out precisely what it is. This can be done by an examination of the subjects' introspective reports of what they experienced during their reactions. The reports were taken down by dictation immediately after the reaction and then re-read to the subject to insure their accuracy. The originals are in German and will be given in German and in English when a complete account of all the experiments is published.

CONSCIOUSNESS OF MEANING

(1) *The meaning has a general character.*

Kerze: "There came to me at once the word 'Light.' This was not a determination of the meaning, but only another word for it. The meaning was entirely general, as if I should say *a* candle, that is, any candle—every possible candle." —Külpe, 9/II.

(2) *The universality of the meaning is not always absolute.*

Ring: "As soon as I saw this word, I experienced an auditory motor stimulus, and immediately in connection therewith the understanding of that which the word signified. This was quite universal without being related to anything in particular—except the limitation to 'finger-ring.' I am distinctly conscious that a finger-ring was intended. I cannot remember an image of any such ring." —Külpe, 13/II.

(3) *The meaning is at times felt to be incomplete, because of an unanalyzed consciousness of what the word signifies.*

Schere: "At first, a feeling of familiarity was present and then a feeling of certainty that I know what the word signifies without having analyzed its meaning any further. First, during the reaction itself there came the further thought 'something with which one cuts.'" —Moore, 9/VI.

Eule: "I knew that the word was something with which I am familiar and knew that from this point I could, at any time, go on and find its more specific meaning. Thereupon I reacted. In the word itself there was something presented to consciousness (mir gegeben) that I cannot further describe."—Frl. Marezoll, 10/VI.

CONSCIOUSNESS OF VISUAL IMAGERY

(1) *The image is particular.*

Sofa: "I have a rather good image and I did not pronounce the word. I see with great precision the brown color and the form of the object—but not of the entire object. I could derive several concepts from this one image. It looks like a large reclining chair. The image would not do for all sofas."—Grüninger, 16/II.

(2) *The image is at times schematic.*

Herz: "I read the word 'heart' and apprehended its meaning. I remembered my task and sought after an image. I projected over the place of the card a heart of regular mathematical proportions. Only the contours were imaged, and these by such an airy line that I question myself whether I had a visual image at all or whether it was an ideal construction, such as one carries out in mathematical thinking."—Scherren, 13/VII.

(3) *The image is at times incomplete in a different way.*

(i) *It is partial.*

Rechen: "First, the meaning, then the image. Nevertheless, I reacted before the image was clear. I imaged a part of a rake. Already I have noted several times that I image the left lower parts of objects. Here I imaged a wooden rake." —Stappen, 17/II.

(ii) *It represents a single definite character of an object.*

Kuh: "I have the meaning and now I must have an image. I then look at an empty spot—no longer at the word. Then there appears the color of the animal. I see 'brown.' But a satisfactory, complete image, I do not obtain. I must exert myself even to obtain the color. I could not take the image for the meaning. I cannot read anything more out of the image than 'brown'—never the meaning 'cow.'"—Grüninger, 16/II.

CONSCIOUSNESS OF MEANING

(4) *The meaning never has sensory characteristics but rather a conceptual determination.*

Geier: "A moment passed before I found the meaning. No auditory-kinæsthetic image was present. I *knew* that it was something that hovers over mountains in the air—even though I did not see the mountains. Visually I imaged only a pair of extended wings and *knew* that something belonged between them." —Frl. Marezoll, 14/V.

Veilchen: Immediately after the word appeared, I had an auditory-kinæsthetic image of it—as I pronounce it. 'Veilchen,' and in connection therewith a knowledge of its meaning (Ein allgemeines Bedeutungswissen), that I can thus explain: a definite species of flower. I dare say that it is this which makes up the content of the meaning—what I actually know about this object during the experiment.—Külpe, 18/V.

(5) *The meaning is often expressed in terms of a definition of general application.*

Dampfschiff: Immediately on the exposition of the word, auditory-kinæsthetic image thereof, and a realization of the meaning in the sense of 'a means of transport by water.' This time there was no trace of any image.—Külpe, 16/II.

(6) *The meaning is never localized.*

CONSCIOUSNESS OF VISUAL IMAGERY

(4) *The image manifests degrees of brightness, color and clearness.*

Rose: "Immediately after the word came I had the auditory-kinæsthetic image of the word and thereupon an understanding for its general signification. Then first came an image—the image of a blossom. Almost nothing of the stem was seen. Colorless, mere differences of brightness in the blossom and the leaves were perceived. A full blown rose. The common form. Image and meaning did not cover each other." —Külpe, 16/II.

Krug: Meaning then the visual image. It was an earthenware jug, bellied out in front—antique as if it had just been dug up.—Lehner, 7/VII.

(5) *The image is often described in sensory terms that would fit only a very definite object.*

Rettich: This time there came to me the image of a radish of medium size. I saw clearly the little hollows in its skin filled with dirt and myself in the attitude in which I cultivate this beautiful variety in my wife's garden. All at once there came to me a poem of Mörike. It is entitled 'The Radish.'—Lehner, 16/II.

(6) *The image has often a definite position.*

Schuh: I had an indistinct image of a laced shoe—the point to the right somewhat behind the plane of the word. A confused consciousness of meaning was also immediately present, which did not coincide with the image. The meaning was even more general than foot covering. It had somewhat the sense of a piece of clothing without relation to a part of the body.—Külpe, 23/II.

Consciousness of Meaning	Consciousness of Visual Imagery
(7) *The meaning is always pertinent to the word.*	(7) *The image is sometimes recognized as not strictly pertaining to the word.* Rettich: The word appeared very strange to me. I think I read something like 'Bettish.' Only later did I get the correct meaning. There came a visual image. The image did not really represent a radish but rather a kind of turnip.
(8) *The meaning is never looked upon as superfluous.*	(8) *The image is often regarded as unnecessary and of secondary importance.* Ochs: I first understood the word as something familiar, as something that I knew what it was. A further analysis of the meaning did not take place. Under the influence of the task, my attention was directed to experiencing an image and then arose the head of an ox with his horns as drawn in the pictures for these experiments.—Moore, 12/VI. Fass: Immediately after looking at the word an auditory-kinæsthetic representation and understanding of its general signification in the sense of a spatial measure. There came also—altogether fleetingly a weak image with a pair of hoops lying on the ground—wholly accessory as if a schema.—Külpe, 16/II.
(9) *The meaning is always present.*	(9) *The image is often lacking.* Such cases could be multiplied indefinitely. Some have already been given.
(10) *The meaning leads regularly to the image.* Nearly always the subjects report the meaning as coming first.	(10) *The image is only occasionally present before the meaning.* Kuh: I believe[1] the image came first—wholly undefined. Very soon thereafter the meaning, immediately after which the reaction.—Stappen, 17/II.
(11) *The meaning comes spontaneously.* Cases enough have already been cited to make this evident. Only occasionally, where the word is read incorrectly, is any effort required to bring out this meaning.	*The image must often be sought.* Flasche: I had the feeling of a considerably retarded flow of imagery, and perceived clearly that I was sharply concenstrated upon my task. I then imagined that I went through Amalien Street and

[1] These cases are very rare. I have found them only with this subject and when he does mention them, it is always with reserve. He says 'I believe' indicating that he is not sure of the observation.

Consciousness of Meaning	Consciousness of Visual Imagery
	had the task to represent to myself a bottle. The representation succeeded but rather poorly. Only the image of the material (glass) and the long form was clear.—Lehner, 3/VII.

A careful consideration of these results will show that the difference between meaning and visual imagery does not consist in any possible difference in the original imagery itself.

If meaning were an early stage in the development of the visual imagery, it might be possible to explain in this way the difference in the reaction times to the two events. A candid consideration of the introspections shows that this is not the case. The universality of the meaning cannot be pictured and is something quite different from the schematism of the image. The incompleteness of the image with a fragmentary character and washed out coloring differs profoundly from the imperfect unanalyzed embryonic stage of the meaning. The image has sensory characters which cannot be ascribed to the meaning—the meaning cognative characters which are utterly foreign to the image. The meaning is a 'knowing' *sui generis;* the image is a sensational element with its own specific character.

The meaning is not the potentiality to visualize. It may have an element of potentiality about it, but it always has an element of actuality which extends from the unanalyzed knowledge expressed by the phrase: "I know what that is" —to the more perfect conception expressed by a definition. The potentiality of the meaning when present is not the same for all meanings. It is a definite potentiality in which the elements of a definition of the object are in subconsciousness. It is not the potentiality to visualize, for the potentiality to visualize (1) depends on a meaning to determine what is to be visualized; (2) results in something different from the actualization of the meaning. The actualization of the meaning leads to the consciousness of a definition which may not even be accompanied by imagery of any kind whatever.

Nor is imagery the tendency of a number of images to

crowd into consciousness. That tendency is sometimes present especially with one of our subjects, but by him it was recognized as something that came after the meaning.[1]

Meaning is often present and one is definitely conscious of it without being conscious of a tendency of images to crowd into consciousness. Meaning is a consciousness of knowledge that has definite characters foreign to the images that tend to crowd into consciousness. Furthermore, where images do crowd into consciousness they have to be known. This knowledge of what the image represents cannot be explained by another image which would itself have to be known.

Meaning, therefore, appears to be a conscious process *sui generis* distinct from imagery.

IV. Consciousness of Purpose and Kinæsthetic Imagery

(*a*) *Quantitative Results*

The instructions to the subject indicate sufficiently the nature of the investigation in this section of the work. These instructions were as follows:

Sie werden nach einem Signal ein Wort zu sehen bekommen. Ich bitte Sie zu reagieren wenn Sie die Bedeutung des Wortes im Hinblick auf den Gebrauch oder die Funktion des damit bezeichneten Gegenstandes erfasst, bzw., wenn Sie eine kinaesthetische oder kinaesthetisch-optische Vorstellung davon gehabt haben.

The words chosen for reaction stimuli in this set were not merely capable of being visualized but represented objects that most of us have often handled as: brush, bell, hat. To represent a word like 'lion' by a kinæsthetic image is to some subjects a very difficult task. Consequently a more appropriate set of words was chosen. Even under the most favorable conditions the kinæsthetic image comes far too late to account for the meaning. It might, however, be claimed that such an image is identical with the consciousness of the purpose of an object. Accordingly the comparison was made between reactions to the consciousness of purpose and those

[1] Cf. *supra*, p. 178. Subject Lehner.

to the awareness of a kinæsthetic image which concerned the object itself. Mere verbal images were excluded. Seven subjects took part in this set of experiments.

The results are shown in the accompanying tables:

Subject Grüninger

Words

Date	Motor Image	T	V	Date	Concept of Purpose	T	V
2/III	Anker	2,084	210	2/III	Stiefel	2,247	699
	Rechen	1,647	647		Koffer	1,389	159
	Gabel	1,929	365		Bürste	1,292	256
4/III	Trichter	2,379	85	4/III	Flasche	1,671	123
	Apfel	2,307	13		Wurst	714	834
	Wiege	2,448	154		Birne	1,255	293
	Eimer	1,690	604		Brief	1,474	74
	Kette	2,398	104		Leiter	1,414	134
	Zwicker	2,101	193		Fahne	2,255	707
	Treppe	2,506	212		Finger	1,458	90
	Hund	3,745	1,451		Kuh	1,474	74
		11)25,234	4,038		Ente	1,942	394
		2,294	367			12)18,585	3,837
					Mean	= 1,548	320
					Median	= 1,466	

Number of times median for concept exceeds reaction time for imagery = 0.

Subject Külpe

Words

Date	Kinæsthetic Image	T	V	Date	Concept of Purpose	T	V
27/II	Ring	1,100	451	27/II	Stiefel	804	306
2/III	Sichel	1,416	135		Auge	1,180	70
	Ring	1,332	219	2/III	Haken	771	339
	Rechen	1,823	272		Hammer	1,822	712
	Bleistift	1,227	324		Bürste	1,346	236
	Würfel	2,579	1,028		Gabel	1,165	55
	Lampe	1,298	253		Feile	1,153	43
	Pickel	1,638	87		Uhr	808	302
		8)12,413	2,769		Stiefel	944	166
		1,551	346			9)9,993	2,229
					Mean	= 1,110	247
					Median	= 1,153	

Number of times median for concept exceeds reaction time for imagery = 1.

With all of our subjects the mean for reaction time to kinæsthetic imagery is longer than that to the concept of purpose. Examining these results critically we find that with some of our subjects in spite of the small number of

SUBJECT LEHNER

Words

Date	Kinæsthetic Image	T	V	Date	Concept of Purpose	T	V
2/III	Würfel	1,083	70	2/III	Feile	997	71
	Lampe	1,515	362		Uhr	1,249	323
	Pickel	1,184	31		Stiefel	1,121	195
5/III	Brief	1,693	540	5/III	Wiege	684	242
	Leiter	1,145	8		Eimer	1,050	124
	Fahne	1,501	348		Kette	733	193
	Flasche	1,980	827		Zwicker	815	111
	Treppe	1,162	9		Finger	1,260	334
23/VI	Stiefel	760	393	23/VI	Brief	941	15
	Uhr	804	349		Leiter	1,076	150
	Feile	941	212		Fahne	960	34
	Wiege	826	327		Flasche	937	11
	Eimer	879	274		Treppe	763	163
	Kette	882	271		Würfel	738	188
	Zwicker	927	226		Lampe	721	205
	Finger	1,170	17		Pickel	775	151
		16)18,452	4,264			16)14,820	2,510
		1,153	266			Mean = 926 Median = 937	157

Number of times median for concept exceeds reaction time for imagery = 6.

SUBJECT MAREZOLL

Words

Date	Kinæsthetic Image	T	V	Date	Concept of Purpose	T	V
14/5	Buch	1,157	493	14/5	Ring	962	353
	Klavier	1,899	249	19/V	Schere	1,215	100
19/V	Eimer	2,148	498		Pinsel	1,942	627
	Korb	1,745	95		Zirkel	1,966	651
	Pinsel	1,643	7		Schlitten	1,404	89
	Zirkel	4,524	2,874		Schere	2,167	852
7/VII	Schlitten	1,573	77		Eimer	3,097	1,782
	Schere	1,071	579	30/VI	Korb	650	665
	Ring	723	927		Buch	857	458
9/VII	Anker	1,884	234		Klavier	807	508
	Besen	1,270	380	7/VII	Bürste	930	385
	Bohrer	1,422	228		Bohrer	990	325
	Bürste	1,218	432		Besen	749	566
	Zwicker	1,557	93		Anker	1,056	259
	Rechen	1,532	118		Haken	939	376
	Horn	1,069	581				
	Meissel	1,616	34				
		17)28,051	7,899			15)19,731	7,996
		1,650	464			Mean = 1,315 Median = 990	533

Number of times median for concept exceeds reaction time for imagery = 0.

SUBJECT MOORE

Words

Date	Kinæsthetic Image	T	V	Date	Concept of Purpose	T	V
	Bohrer	1,453	217		Handbeil	781	36
16/VI	Spaten	1,129	541	16/VI	Säbel	1,162	345
	Haken	1,628	42		Pinsel	592	225
	Messer	1,796	126		Besen	539	278
18/VI	Bürste	1,772	102		Nadel	918	101
	Zange	1,396	274	18/VI	Rechen	815	2
	Handbeil	1,572	98		Feile	1,046	229
9/VII	Pinsel	1,914	244		Bohrer	1,004	187
	Pfeil	1,222	448	9/VII	Spaten	564	253
	Besen	1,480	190		Haken	836	19
	Wage	1,461	209		Hammer	1,215	398
	Brille	1,896	226		Handschuh	412	405
	Feile	2,071	401		Löffel	635	182
	Kerze	1,459	211		Schlitten	1,001	184
30/VII	Ring	2,234	564	30/VII	Leiter	719	98
	Zange	1,722	52		Schlüssel	669	148
	Bohrer	1,564	106		Rechen	967	150
	Haken	1,888	218		Spaten	822	5
	Schere	1,729	59		Pinsel	1,028	211
	Zirkel	2,014	344		Bürste	621	196
		20)33,400	4,672			20)16,346	3,652
		1,670	234			Mean = 817	183
						Median = 818	

Number of times median for concept exceeds reaction time for imagery=0.

SUBJECT STAPPEN

Words

Date	Kinæsthetic Image	T	V	Date	Concept of Purpose	T	V
	Kerze	4,308	2,915		Auge	1,199	449
	Haken	528	865		Säge	682	68
28/II	Bürste	644	749	28/II	Sichel	697	53
	Würfel	465	928		Gabel	814	64
	Sense	1,024	369		Feile	362	388
		5)6,969	5,826			5)3,754	1,022
		1,393	1,165			Mean = 750	204
						Median = 697	

Number of times median for concept exceeds reaction time for imagery=3.

experiments we can say definitely that the concept of purpose comes quicker than the kinæsthetic imagery. With these subjects the median for the concept of purpose was shorter than everyone of the reaction times to kinæsthetic imagery. With one subject, one out of eight reactions to kinæsthetic imagery was shorter than the median; with another two out of

Subject Tannhäuser

Words

Date	Kinæsthetic Image	T	V	Date	Concept of Purpose	T	V
	Bohrer	1,492	231		Klavier	1,314	456
	Schlüssel	939	322		Bürste	749	109
	Trichter	1,527	266		Fernglas	749	109
	Bleistift	1,367	106		Haken	1,069	211
	Trommel	1,088	173		Leiter	829	29
30/VII	Brille	1,903	642	30/VII	Kerze	885	27
	Rechen	1,327	66		Pickel	1,071	213
	Tasche	1,255	6		Zange	1,816	958
	Wage	1,378	117		Ring	785	73
	Hammer	1,005	256		Schlitten	600	258
	Handschuh	1,158	103		Feile	763	95
	Besen	1,173	88		Spaten	554	304
	Dolch	855	406		Brief	554	304
	Horn	1,011	250		Anker	739	119
	Auge	2,334	1,073		Eimer	1,114	256
	Brunnen	2,216	955		Hut	824	34
	Geige	694	567		Flasche	976	118
	Fass	2,006	745		Glocke	717	141
	Hahn	2,082	821		Fächer	648	210
	Beil	1,576	315		Finger	1,006	148
31/VII	Messer	831	430	31/VII	Fahne	875	17
	Lampe	883	378		Meissel	834	24
	Koffer	797	464		Korb	952	94
	Buch	1,009	252		Kette	817	41
	Hobel	1,007	254		Kamm	816	42
	Handbeil	707	554		Schrank	637	221
	Schuh	848	413		Sense	776	82
	Ofen	849	412		Pfeil	700	158
		28)35,317	10,665		Nadel	720	138
		1,261	381			29)24,889	4,989
					Mean	= 858	172
					Median	= 816	

Number of times median for concept exceeds reaction time for imagery = 2.

twenty-eight. With one of our subjects the matter looks a little doubtful; six out of sixteen are shorter than the median. With another subject[1] the results are too few and scattered to give any quantitative basis for judgment.

The question is one where individual differences are likely to play a part. Those who readily form kinæsthetic imagery may be able to obtain such an image more quickly than they can *think* of the purpose of the object. To what extent this is true cannot be decided from the present results.[2]

[1] It was impossible to get more experiments from this subject. He left the day after the series above reported and did not return in the summer semester. They are more of the nature of a preparatory series than final results.

[2] When a short abstract from this paper was read last December at the meeting

Taking all the results together only 12 out of 105 reactions to kinæsthetic imagery were shorter than the median of the various subjects' reaction-times to the concept of purpose.

(*b*) *Introspective Data*

Turning now to the introspective results, we find that the concept of purpose and the kinæsthetic image are very clearly differentiated. The concept of purpose differs from the simple meaning in that it does not come with the same necessity. It is the result of the subject's task—not of the mere exposition of the stimulus. The same is true of the kinæsthetic image. Both follow upon the awareness of the simple meaning. Neither is a necessary prelude nor a sequence of the other. The task "image" or "concept" is the main factor in determining which is to appear.

The following are some of the more noteworthy introspective differences between the two.

(1) *The concept of purpose is expressed in non-sensory conceptual terms.*

Zwicker: "I imaged my own eye glasses and had clearly a consciousness of concave glasses. I was further conscious of the fact that these glasses must refract the rays of light according to a definite law that the image may still fall upon the retina—even though the lens is incapable of doing it this service. I then formulated the purpose of eye-glasses as: 'The correction of an error of refraction.'"—Lehner, 5/III.

(2) *The concept of purpose sometimes involves the consciousness of the relation of the object to other things.*

Gabel: "Immediately after the appearance of the word an auditory-kinæsthetic image thereof. Then came the know-

(1) *The kinæsthetic image always describes some kind of act involving a use of the muscles.*

Sichel: "Immediately after the word appeared I had an auditory-kinæsthetic image of it. Following this I constructed a visual and weak kinæsthetic image thereof in this manner. I held a sickle in my right hand and made movements therewith as if I were cutting grass. Thereupon I reacted."—Külpe, 2/III.

(2) *This was not noted in the description of the kinæsthetic imagery.*

of the Southern Society for Philosophy and Psychology, Professor Ogden stated that he had reported some years ago at one of the meetings a series of experiments similar to the present in all details. He never published his results, but they were identical with my own. In the interests of a better insight into individual differences it is to be hoped that Professor Ogden will some day give us the advantage of his unpublished results.

ledge that the fork is an instrument for eating, accompanied by a weak visual image of a fork. I was also conscious that 'fork' stands in relation to 'knife.'"—Külpe, 2/III.

(3) *The concept of purpose though often restricted to one of various possible ends has always a certain generality.*

Kette: "I pictured to myself a tolerably strong chain and remembered from the days of my youth that such chains were used to tie animals in their stalls. I saw the whole situation of that day rise up before me."—Lehner, 5/III.

(4) *The consciousness of purpose seldom stops with a means but rests in a concept conceived of as the object's end.*

Uhr: "Immediately after the appearance of the word I had an auditory-kinæsthetic image, then the thought: 'The clock must be wound up!' and then the further thought: 'The clock tells the time!' Then I reacted. Weak visual image of a clock on a wall."—Külpe, 2/III.

(5) *The concept of purpose, even though delayed, comes as a natural development of thought about the object.*

(3) *The kinæsthetic image is often perfectly definite and limited to an individual act in a certain time and place.*

Pickel: "I imaged a pick-ax, such as is used for working hard ground and saw myself in my garden in the act of lifting it in the air. The consciousness of the purpose of a pick-ax is a psychological process which cannot be identified with the act of lifting it."—Lehner, 2/V.

Wiege: "The meaning aroused the image of a cradle. I go back in thought to my childhood and feel how I rock my brother. The kinæsthetic image in this case contains a great part of the purpose."—Grüninger, 4/III.

(4) *The kinæsthetic image regularly concerns an art which is a means to the object's end.*

Lampe: "I imaged the lamp that I use in my dwelling, and saw clearly that it did not burn brightly enough, and then imaged the turning up of the wick. The kinæsthetic image of the movement cannot be identified with the consciousness of purpose."—Lehner, 2/III.

Trichter: "Immediately after the simple meaning of the word, I had the visual image of a funnel and then the kinæsthetic image of laying hold of it with my right hand and placing it over an opening. Here also the kinæsthetic image falls short of being the fulfilment of the purpose. For I think that the funnel is the instrument by means of which I pour fluid through an opening, and my image is only the placing of the funnel in the opening."—Grüninger, 4/III.

(5) *The kinæsthetic image is often forced and is superfluous to the understanding of the function of the object.*

Handbeil: "I soon understood the word, but the simple consciousness of meaning was forced into the background of consciousness by the task. I can express this simple consciousness of meaning by the sentence: ' I know well what that is!' Then I asked myself under the influence of my task: 'What purpose does it serve?' Then there came to me the clear concept that it is of use in cutting wood. With this concept of purpose were some broken, confused words. I do not know whether they were German or English. There was also a dark blurred image of an island in Lake George, where I have often cut wood in summer."—Moore, 16/VI.

(6) *The concept of purpose, though at times more or less restricted, never miscarries entirely.*

Fahne: It was rather difficult for me to connect a kinæsthetic image with the word. At first I imaged a flag as I saw one recently waving on a little tower in Leopold Street. But I said to myself at once, 'This waving is not a kinæsthetic image.' Then I imaged to myself how I would place this flag on the little tower. That the purpose of the flag is not covered by my motor image of it, goes without saying."—Lehner, 5/III.

(6) *The kinæsthetic image is not always pertinent to the purpose of the object.*

Bohrer: "Again the meaning first and then a visual image of the object—of a whole situation. I attempted to screw a drill through the wall, and instead of that I lifted the whole wall with the drill."—Frl. Marezoll, 9/VII.

V. Meaning and the Word

(*a*) *Quantitative Results*

In the perception of the meaning of words, subjects often spoke of the meaning being associated with an auditory-kinæsthetic verbal image of the word itself. No attempt was made to find out by reaction time the temporal relations of the verbal image and meaning in the perception of printed words. From the introspective results no definite answer can be obtained. The two are so close together that they appear simultaneous. One might, however, surmise that since the word must be read, in order that it may be perceived and understood, verbal sensations or verbal imagery are likely to come prior to understanding.

On account of the close connection with the sensations involved in reading and the understanding of printed words, such material presents no little difficulty in studying the

necessary relations between verbal imagery and meaning. Pictures seemed to offer a more favorable material for study. If meaning is the kinæsthesis of speech, then the knowledge that a picture before me represents a tree should come when I name the picture and not before. A series of reaction times for the naming of pictures and perceiving the meaning of pictures should give approximately identical results. Three of our subjects took part in these experiments.

With all three subjects there is strong evidence that in general it takes longer to react to the word than to the meaning. The means for reaction to the word are, in every case, longer than those for meaning. This excess is also

Subject Lehner

Pictures

Date	Word	T	V	Date	Simple Meaning	T	V
9/III	Baum	845	214	9/III	Säge	492	1
	Uhr	630	1		Katze	419	74
	Lilie	968	337		Hahn	251	242
	Sichel	638	7		Ring	923	430
	Käfer	626	5		Eimer	500	7
	Hammer	794	163		Krone	629	136
	Treppe	601	30		Pfau	416	77
	Sense	726	95	19/V	Hobel	517	24
	Kamel	698	67		Spinne	579	86
	Mitra	775	144		Schlitten	572	79
19/V	Würfel	840	209	26/V	Fernglas	704	211
	Frosch	649	18		Haue	718	225
	Pinsel	689	58		Krug	536	43
26/V	Apfel	708	77		Stuhl	380	113
	Uhr	493	138	20/VII	Baum	673	180
	Wiege	780	149		Uhr	547	54
20/VII	Katze	485	146		Lilie	334	159
	Ring	720	89		Sichel	383	110
	Haken	563	68		Hammer	558	65
	Säge	594	37		Sense	349	144
	Fernglas	410	221		Kamel	392	101
	Pfau	376	255		Käfer	460	33
	Krone	713	82		Pinsel	468	25
	Eimer	375	256		Treppe	327	166
	Hobel	598	33		Frosch	411	82
	Stuhl	373	258		Würfel	400	93
	Haue	623	8		Wiege	391	102
	Schere	560	70		Apfel	553	60
	Krug	474	157		Korb	344	149
					Mitra	572	79
		29)18,324	3,392			30)14,798	3,350
		631	117		Mean	= 493	112
					Median	= 480	

Number of times median for meaning exceeds reaction time=6.

Subject Külpe

Pictures

Date	Word	T	V	Date	Simple Meaning	T	V
9/III	Horn	1,020	98	9/III	Pferd	525	108
	Sofa	767	155		Bürste	510	123
	Rechen	824	98		Haus	798	165
	Dampsfchiff	769	153		Ente	308	325
	Kette	825	97		Fahne	673	40
	Zwicker	738	184		Flasche	967	334
	Finger	843	79		Trichter	570	63
	Stiefel	1,692	770		Bohrer	659	26
	Dolch	837	85		Uhr	524	109
	Kerze	1,718	796		Lilie	957	324
	Lilie	957	35		Hahn	573	60
	Sichel	834	88		Käfer	767	134
	Haken	759	163		Hammer	722	89
	Ring	332	590		Löwe	327	306
		14)12,915	3,391			14)8,880	2,206
		922	242			Mean = 633 Median = 616	157

Number of times median for meaning exceeds reaction time to word = 1.

Subject Marezoll

Pictures

Date	Word	T	V	Date	Simple Meaning	T	V
26/V	Korb	959	48	26/V	Zirkel	998	341
	Schere	825	86		Eimer	643	14
	Pickel	1,862	951		Stuhl	463	194
	Apfel	622	289		Sichel	1,009	352
	Uhr	781	130		Trommel	561	96
	Wiege	729	182		Dampfschiff	463	194
	Tasse	1,175	264				
25/VI	Maske	873	38	25/VI	Windmühle	526	131
	Lyra	782	129		Kirsche	560	97
	Engel	736	175		Zither	796	139
	Ochs	671	240		Kette	739	82
	Mitra	913	2		Fahne	501	156
					Würfel	628	29
		12)10,928	2,534			12)7,887	1,825
		911	211			Mean = 657 Median = 594	152

Number of times median for meaning exceeds reaction time for word = 0.

greater than the mean variation. With one subject in 29 reactions to words, only 6 were shorter than the median for meaning; with another, 1 in 14; with another, 0 in 12.

(*b*) *Introspective Data*

Turning to the introspective results we find them in accordance with the quantitative measurements. Time and

time again, whether the task were meaning or word, the same sequence of events was perceived, viz., (1) meaning, (2) word, (3) reaction. Often, however, when the task was meaning, the word was reported as coming during or after reaction.

Some special points of difference between the word and the meaning are given below.

(1) *The meaning leads to the word—the designation of the picture.*

Frosch: "The meaning was first present. I felt a strong striving for the word, as it were from various sides of the drawing. The reaction followed after the entrance of the word."—Lehner, 9/V.

(1) *The word never leads to the meaning.*

(2) *A meaning cannot be lacking if the subject names the picture—no matter what the task.*

(2) *The word may be lacking when the task is meaning.*

Eimer: The word did not appear at all. Various memories were in the background of consciousness.—Frl. Marezoll, 26/V.

(3) *The meaning is what it is by its own right. It is never said to have a meaning.*

Pferd: "Immediately after I saw the picture I experienced a tone of familiarity and knew what this picture represented. At the same time, with the reaction came the word 'Pferd.' I did not react to the word. The tone of familiarity was related not to the picture, but to what it signified. The picture was a symbol of real objects and its signification consisted herein, viz.—to point to them."—Külpe, 9/III.

(3) *The word may have a special meaning of its own; e. g., the word has a more general meaning than that of the picture.*

Engel: "Immediately a memory image. After this image came the word. I knew that the meaning of the word was more general than that of the picture."—Frl. Marezoll, 25/VI.

(4) *The meaning is sometimes designated by a word which is known to be inappropriate.*

Lilie: "First I recognized in the picture a flower, then I named it by mistake 'Tulpe.' I knew that 'Tulpe' did not fit the picture. Then through the form of the flower, etc., I was occasioned to say "Glockenblume."—Lehner, 9/III.

(4) *The word is never designated by a meaning.*

VI. Influence of the Observer's Attitude

When a short abstract of this paper was read last December at the meeting of the Southern Society of Philosophy and Psychology, it was suggested that the difference in reaction time to meaning and imagery is to be explained by a difference in the attitude of the subject. He reacts quicker when told to react to meaning, not because the meaning is something different from the imagery but because he himself assumes a different attitude.

This objection implies that there is no real difference between meaning and imagery, but that when we call them by different names the subject, for some obscure reason, assumes such a different attitude that it markedly influences his reaction time. The objector in other words does not wish to admit a difference between meaning and imagery, and refers the difference in reaction time to an unexplained and perhaps inexplicable mystery.

To say the least, this explanation is highly improbable. For supposing there is no such thing as a special 'meaning process' and that the accruing image is identical with the meaning, then the task of the subject in the two sets of reactions is really identical. It is simply called by different names. If that were the case, then the subject ought (1) to have a real difficulty in distinguishing his two tasks. (2) He ought to give introspective reports identifying the two procedures. (3) The reaction times ought to be identical within the limits of the probable error.

None of these things were so, but on the contrary (1) The tasks were readily distinguished. (2) The introspective reports clearly separate the two processes. (3) The reaction times are markedly different.

All this tends to render highly improbable, if not impossible, the explanation which suggested that the difference in the reaction times is not to be explained by a real difference in the tasks, dependent on a difference between meaning and imagery, but is due entirely to the difference in the attitude of the subject. In fact, it is very hard even to imagine a

mental mechanism which would produce two separate attitudes with such different effects in the reaction-times, if that to which the subject takes an attitude is in both cases merely one and the same thing that the experimenter calls by a different name.

Let us, however, go a step further. Our subjects reacted to visual and kinæsthetic images. If we wish to compare the reaction times in this case we will find them markedly different. Is it possible to explain that difference by a difference in the attitude of the subject?

If we should argue visual imagery is distinct from kinæsthetic (1) because the subject distinguishes two different tasks when told to react to the one or the other; (2) because the introspective reports clearly separate the one from the other; (3) because the reaction times to visual imagery are much shorter than to kinæsthetic imagery, no one would doubt the validity of the argument. When, however, the same argument is made in regard to imagery and meaning, it is called in question and the attempt is made to explain away the difference by ascribing it to a difference in the attitude of the subject. If, however, the difference in the attitude of the subject is not the real explanation in the latter case, but a real difference between visual and kinæsthetic imagery, then this difference in the attitude of the subject cannot, without any more ado, explain the shorter reaction time for meaning as compared with imagery.

Furthermore, the difference in attitude itself must be explained. Granted that there is a difference in attitude, what is the most likely explanation for the fact? The first thing that comes to mind is that in the two sets of conditions the subject is taking an attitude to two different things. If that is the case then, meaning and imagery must be distinguished. But how distinguished—as two different mental processes or as two aspects of one and the same process?

In the sequence of events that follow the exposition of the stimulus word, there may be, if you wait long enough, not only visual but also kinæsthetic imagery. Are these aspects of one and the same mental processes, or specifically dif-

ferent items in a definite series of events? Reasons have already been given for distinguishing them. These reasons point to events that are qualitatively distinct, and the distinction can scarcely be called in question. But the very same reasons point to meaning as qualitatively distinct from imagery. When, furthermore, one considers the fact that in the understanding of words the meaning process is never absent, but that visual and kinæsthetic imagery may both be lacking, there is an added reason why meaning should not be identified with an aspect of visual or kinæsthetic imagery.

Furthermore, a difference in the attitude of the observer cannot be made the sole reason for the difference in the reaction times.

(i) In the set of experiments referred to in the beginning, the subject's task was to observe and remember a series of words, pictures or objects. Nothing was said about attending to meaning or imagery. He had simply to report what he had experienced—whatever that might be. Here the question of a difference in the "set" of the observer does not enter at all. In these experiments, the subjects reported that in the perception of words, meaning preceded imagery. This suggested the problem of an objective test of the accuracy of the introspection. The reaction time experiments followed, and confirmed with entire satisfaction the introspections of the earlier series.

(ii) In the reaction time experiments no matter what the task—whether the subject is in the meaning attitude or the image attitude, he regularly reports meaning as coming prior to imagery. If the difference in the 'set' of the observer were the sole reason for the difference in reaction time, we should not expect that no matter what his 'set' he would nevertheless observe a rather constant temporal relation between meaning and imagery.

The introspective results and the reaction times are supplementary. When taken together they leave no doubt that we have really been investigating the temporal relation of meaning and imagery.

VII. The Context Theory of Meaning and the Temporal Relations of Meaning and Imagery

It may now be asked: Whom does all this concern? Who maintains that imagery is meaning? In spite of a certain modification of the image theory of meaning, Professor Titchener's context theory cannot account for the experimental facts brought out in his own and other laboratories. From an analysis of his theory it is apparent that he maintains that meaning is often identical with imagery. In fact under the conditions of our experiments the images and words that followed upon the sensations of the stimulus words and pictures were actually the context. Analogous conscious states have been reported by Cornell observers as the meaning under somewhat similar conditions. But they did not take into consideration the temporal relations of meaning and imagery.

A brief analysis of the context theory of meaning will show how intimately it is concerned with the temporal relations of meaning and imagery.

(*a*) *Outline of the Theory*

"Meaning, psychologically, is always context."[1] Such is the definition that Professor Titchener gives to a fact of consciousness with which the modern psychology of thought is now interested.

What is context? Context in English is a word used to signify the setting of a sentence or a quotation—its relation to what the author has written before and after the passage in question. Titchener lays particular stress upon what comes after in the definition of psychological context. "Context, in this sense, is simply the mental process which accrues to the given process through the situation in which the organism finds itself." A sensation by itself has no meaning—neither has an image. When a second mental process accrues to a former one—this second mental process is the meaning of the first one. It does not produce a new something called mean-

[1] 'A Text Book of Psychology,' New York, 1911, p. 367.

ing, it is the meaning. "One mental process is the meaning of another mental process if it is in that other's context."[2]

What are the mental processes that accrue to others and thus constitute their meaning? Originally the secondary process which constituted the meaning was a group of sensations coming from a bodily attitude of the organism. If the animal took an attitude of defence the kinæsthetic sensations thus aroused did not exactly mean—did not signify that something to be feared was at hand. The whole complex of sensations involved constituted the meaning "something to be feared."

At the present day, however, the human mind has passed beyond the elementary stage of the primitive organism. The essential difference between present human intelligence and its early prototype consists in the use of imagery as well as sensations for the constituents of meaning. "Image has now intervened upon sensation and meaning can be carried in imaginal terms."[2] Thus spoken and written language has become possible. A sensation arouses an image and the image—the psychological process accruing to the sensations—is the meaning of the sensation.

Various types of mind exist. Each has a special tendency to form some kind of imagery in understanding sensations. Indeed "If we were to make serious work of a differential psychology of meaning, we should probably find that in the multitudinous variety of situations and contexts, any mental process may possibly be the meaning of any other."[3]

It is Professor Titchener's opinion however that of all the possible types of supplementary mental processes, two are of special importance: kinæsthesis and verbal images. Indeed he pushes the verbal theory so far as to say: "The words that we read are both perception and context of perception, the auditory kinæsthetic idea is the meaning of the visual symbols."[4]

[1] *Op. cit.*, p. 367.

[2] *Op. cit.*, p. 367.

[3] 'Lectures on the Experimental Psychology of the Thought Processes,' 1909, p. 178.

[4] 'A Text-Book of Psychology,' p. 368.

Thus far, Professor Titchener's theory is entirely psychological. But in order to meet all possible contingencies arising from introspections that he or others may report, where meaning shows no trace of a sensory conscious element —a physiological factor is introduced.

Meaning is not always conscious; *i. e.*, the imaginal supplement to the sensation is not always to be found even by the most careful introspection. In such cases the sensory supplement exists—it is a physiological process in the nervous system.

Professor Titchener thus summarizes his theory of perception:

"Our account of the psychology of perception is now, in the author's view, complete. It has embraced four principal points:

"First, under the general laws of attention and the special laws of sensory connection, sensations are welded together, consolidated, incorporated into a group.

"Secondly, this group of sensations is supplemented by images.

"Thirdly, the supplemental group has a fringe, a background, a context; and this context is the psychological equivalent of its logical meaning.

"Fourthly, meaning may lapse from consciousness and conscious context may be replaced by a non-conscious nervous set."[1]

The type of meaning in the third caption is decidedly different from that given a few pages previous. There meaning is context—context is the mental process that follows upon and accrues to another mental process. The examples given are the images spoken of in the second caption. Here we suddenly find that meaning does not lie in the advening images—but in their fringes.

To harmonize this new idea with what has gone before we may suppose that if meaning is conscious (in the sense of being conscious described by Titchener) it is given by the context which may be (*a*) a second group of sensations, (*b*)

[1] 'A Text Book of Psychology,' 1911, p. 371.

an image or a group of images, (*c*) the fringe or background of such images—the fringe itself being always understood as some kind of sensory element or elements, (*d*) various combinations of (*a*), (*b*) and (*c*).

(*b*) *The Evidence for the Theory*

In the interests of simplicity we may leave aside the speculations about meaning in the primitive organism and confine ourselves to the explanation of the fact of meaning as we experience it.

On what then, may we ask, is the statement based that meaning is context—that it is a 'sensory complex *B*, following upon sensation or image *A*.' The points of evidence are:

1. Introspection shows that when a word or a sentence is understood and careful search is made we always find some kind of imagery—verbal, kinæsthetic, visual, etc.

Granted that this is so what does it prove? Nothing more than this. In the complex of mental processes called up by the task of understanding a word or sentence imagery is present. It does not show that this imagery is the meaning—which is the very point in question.

Titchener says: "The meaning of the printed page may now consist in the auditory-kinæsthetic accompaniment of internal speech; the word is the word's own meaning."[1]

He then refers in a note to introspections in the studies of Watt and of Messer which speaks of meaning being simultaneous with auditory-kinæsthetic imagery. But such a citation is not to the point. The fact that one thing accompanies another is certainly no evidence that the two are identical.

2. Analysis shows no evidence of 'imageless thoughts.'

What analysis shows is the fact of meaning. Many observers have maintained that in their consciousness of meaning sensational elements are lacking. Professor Titchener in his analysis finds also the fact of meaning and giving to the students in his laboratory the task of reporting every mental process that they can observe, he obtains experiences

[1] 'Lectures on the Experimental Psychology of the Thought Process,' p. 177.

far richer in sensational elements than are elsewhere found. Given the task, 'find imagery,' and it will certainly come. And if the subject be told to look for imageless imagery, it will not be found. Meaning and imagery however, have been found both by Professor Titchener and a number of other observers. Facts are common property. It remains for Professor Titchener to prove that meaning is identical with the concomitant or subsequent imagery. This he has not done.

The context theory of imagery demands imagery, when meaning is present. If meaning equals imagery, imagery equals imagery. No imagery—no meaning, must be the conclusion to be drawn from this theory. Nevertheless Professor Titchener shrinks from admitting all that is involved in his doctrine. Why? Because he himself has observed that there are times when he experiences meaning and is not conscious of imagery. He himself, therefore, in spite of the ease with which he images things and situations, has experienced the very state of mind the existence of which he denies.

"In rapid reading, the skimming of pages in quick succession; in the rendering of a musical composition, without hesitation or reflection, in a particular key; in shifting from one language to another as you turn to your right or left-hand neighbor at a dinner table: in these and similar cases, meaning has time and time again, no discoverable representation in consciousness."[1] No discoverable representation in consciousness means no sensational element—no sensational or imaginal complex.

What is Professor Titchener's explanation of such "imageless thoughts" that come to him as he skims over the pages of a book? He has found "imageless thoughts," what then is to be done with them? Explain them away and then deny their existence. How explain them away? Refer them to the nervous system? Meaning here is not imagery for no imagery is present. What is it then? A physiological process, without any conscious accompaniment. Why without any conscious accompaniment? Because by hypothesis the

[1] 'A Text-Book of Psychology,' p. 369.

only conscious processes that come into consideration are sensations and these are lacking.

On the one hand, we have an hypothesis; on the other, a fact—the imageless consciousness of meaning (imageless thoughts) in rapid reading. The fact cannot be accounted for by the hypothesis; therefore Professor Titchener denies the fact. My consciousness of meaning is unconscious. I do not think but my nervous system is thinking for me.

The reference of imageless thought to an unconscious physiological process in the nervous system brings us to a third point in the evidence for Professor Titchener's theory.

(3) "Our psychology is to be explanatory and our explanations are to be physiological."[1]

Adherence to this principle and the ruling out of facts that it cannot explain, give to Professor Titchener's theory a certain plausibility.

What can be referred to the nervous system is explained What cannot be referred to the nervous system is not explained. It is in fact inexplicable. There must be a mistake in the observation. It must be explained away. The nervous system with its sense organs and its centres, can apparently take care of sensations and images. It gives us the sensational elements of our conscious life and apparently excludes anything like imageless thinking. If then we are to explain 'imageless thought' we must analyze it in terms of the elements given by the nervous system, or else explain it away altogether.

Such a procedure, however, places empirical psychology not only under the dominion of metaphysics, but subjects it to one particular metaphysical theory. Under such conditions an impartial empirical study of the mind becomes impossible. Let us first study the facts of consciousness and then build up our metaphysical theories.

Professor Titchener is right in demanding that the science of psychology should be explanatory; he is wrong in maintaining that everything must be explained in consonance with a particular metaphysical theory.

[1] 'A Text-Book of Psychology,' p. 370.

As a matter of fact neither Professor Titchener nor anyone else knows the limitations nor the possibilities of the nervous system. Nor does anyone know, for that matter, what the nervous system may be called upon to do if it is to explain the facts of our conscious life. We do not know all about the facts of consciousness and until we do, explanatory psychology must be careful. We do not know all about the nervous system and it is not wise to distort the fact of consciousness to fit the narrow outlines of our present horizon.

Let us first investigate the facts of consciousness without any timidity about their ultimate explanation. Let us first find out what we have to explain, and then explain it.

The context theory of meaning is not based entirely upon such general considerations as we have picked out from Professor Titchener's writings. There are a number of experimental studies that have been put forward as tests in confirmation of the theory.

Of these, we may analyze two, leaving a more complete account of the literature to a full report of our experiments which we hope to publish later.

Helen Clarke,[1] in an article on 'Conscious Attitudes' took up the problem of the understanding of words and sentences. She confirmed the reports of other observers that 'often the images are adequate, irrelevant or even coı radictory' (p. 241). The inadequacy she explained by saying that 'we have no criterion save the facts themselves, by which we can decide how clear or complete an image must be in order to carry a meaning' (p. 241). The contradictory character she accounted for by pointing out that in every one of her cases there was 'sufficient connection between the logical meaning of the word, and the psychological context of the act of understanding, for the latter to carry a general meaning' (p. 242). The fact of irrelevancy, she said, was less easy to explain.

Miss Clarke therefore seems to be conscious of the fact that words have a logical meaning which cannot be identified with the imagery that they evolve. She distinguishes be-

[1] *Am. J. of Psychol.*, XXII., pp. 214–249.

tween the word—the imagery that it evolves—and the meaning that is carried. She finds also that imagery is often irrelevant. Irrelevant to what, we may ask? To the meaning. She therefore realizes a difference between the psychological process called an image and another something of which she is also conscious and which may be termed the meaning of the word. Miss Clarke[1] seems to look upon general meaning as a logical something of which no account need be taken in psychology. If, however, the task of psychology is to investigate all conscious processes, logical meaning cannot be ruled out as 'outside the sphere of psychology.'[2] For "logical meaning" is conscious. Its nature is therefore a psychological problem. It is that something to which the imagery is often inadequate, irrelevant and contradictory. Miss Clarke has implicitly at least recognized it as a conscious state, distinct from imagery.

Edmund Jacobson[3] investigated by the Method of Introspection (1) The Perception of Letters, (2) The Meaning of Words, (3) The Understanding of Sentences. The instructions to his subjects (three observers) were as follows:

I. Give a minute account of all the mental processes you experience in their temporal order of sequence.

II. Put direct description of conscious processes outside of parentheses, and statements concerning meanings, objects, stimuli and physiological occurrences inside.

The experiments on the perception of letters showed that under the instructions given their meaning is usually accompanied by the arousal of what Jacobson termed designatory processes, viz., kinæsthetic or auditory sensations or both. Jacobson calls attention to the fact that "The main point to note is that the precise statement of meaning is by no means easy." Nor does he state anything more definite as to what the meaning of a letter is.

The experiments with the meaning of the words were made as follows: "A written word was laid before the observer for a period of one minute. He was instructed to fixate the

[1] Along with Geissler, *Am. J. of Psychol.*, XXIII., p. 194.

[2] Cf. Geissler, *l. c.*

[3] *Am. J. of Psychol.*, 1911, XXII., pp. 553-577.

word, to utter it with quick repetition and to get at its meaning. The concluding ten seconds were marked off by signals; and the observer's task was to report what occurred in consciousness during the particular interval." The observer reported two kinds of imagery: (*a*) That which appeared as the carrier of the meaning and (*b*) that which appeared as irrelevant. No logical or psychological test could be found to distinguish between the relevant and irrelevant imagery.

The conclusion of Jacobson was "that the conscious meanings brought out in these experiments are not perfect and static logical meanings of definition. . . . Logically, the representation of meaning is inadequate; psychologically, it is adequate to the demands of the occasion" (pp. 568–569).

In his experiments on the meaning of sentences, Jacobson found cases in which (1) an automatic reading was followed by a perception of the meaning identified with images called forth by the experiment. (2) Cases in which the meaning did not come to the subject at all in spite of a wealth of visual, organic, kinæsthetic and tactual sensations. (3) Cases in which the visual and auditory images and sensations from reading were the sole processes present in consciousness —and yet the sentence had meaning. Jacobson concludes: (1) "Wherever there is meaning there are also processes," *i. e.*, sensations and images of one kind or another. (2) "The correlated meanings and processes are two renderings from different points of view of the same experience."

The first conclusion seems established by the introspective reports, but it holds only for the conditions of these experiments where ample time is given for images to appear and the task is set to report primarily mental processes, *i. e.*, sensations and images; and secondarily, in parentheses, to note meaning as it arises.

The second conclusion: (which is really the "crux" of the whole situation) meaning is an aspect of sensation and imagery, is simply stated and the reader is left to judge for himself on what evidence the conclusion is based. The only evidence in his paper for such an indentification is to be sought in the fact that his subjects, as a rule, were not satisfied that they

had anything that corresponded with their idea of meaning till relevant imagery was present. This simply shows that meaning in the Cornell sense is not present till such imagery arises. From Jacobson's own data, it appears, however, that meaning in a broader sense must have been present when meaning in the Cornell sense was denied. When Dr. Geissler, instructor in psychology at Cornell, for 3 seconds, looked at the sentence, "Did you see him kill the man?," and then declared at the end "No meaning all the way through," we can only conclude that "meaning" must have been taken in a very restricted sense. When again he looked at the sentence, "The iron cube fell heavily on the floor," reads it as so many meaningless words, and then on rereading obtains the meaning, a very loud sound, the time of the whole procedure being 4.5 seconds, the conclusion is strengthened that during the experiment, he was seeking for a meaning in the sense of an imaginal representation. In this sense, and in no other, is Jacobson's conclusion warranted. An imaginal representation is some kind of imagery. The sweeping conclusion that meaning is an aspect of imagery requires the proof of another proposition, namely that all meaning consists in imaginal representation.

The data of this piece of introspective work is incompatible neither with the data nor the conclusions of the Külpean school. Indeed it has confirmed the fact that the meaning of a sentence may be present when the sole processes present in consciousness are the visual and auditory images and sensations from reading. And if it be true that on certain occasions, as in Geissler's case, these same processes were present and the meaning was really absent, one should conclude that they cannot be identical with the meaning. In like manner, a physician refuses to admit that a definite microörganism is the cause of a disease—if at times it is found when the disease does not occur, and the disease occurs when the organism is absent. Jacobson should therefore have admitted that there are times at least when meaning is not a mere aspect of sensations and images.

Professor Titchener looks upon the chief value of Jacob-

son's work in making the distinctions between the mere statement that meaning is present and the analytic description of the psychological part of meaning. He says that "He finds no specific 'meaning process' underlying the statement of meaning."[1]

True it is that Jacobson found no special sensory or imaginal process as the habitual carrier of meanings, but he did not prove that meaning is not itself a conscious process. In fact, his experiments seem rather to confirm the conclusion that meaning is not imagery, but something else altogether.

Had the Cornell School taken cognizance of the temporal relations of meaning and imagery, the context theory of meaning would have been profoundly modified. Imaginal terms may accrue to incoming sensations and constitute by definition their context. Do they constitute their meaning? A determination of the temporal relation that imagery bears to meaning shows that this is impossible. What comes after another cannot be said to cause, or constitute it, or be identical with it. Meaning, therefore, is not context. What is it—a mere negation? Not at all. It is a definite mental process *sui generis*. What are its qualitative characters? Some of these have been already indicated. A further development of the concept will be given with the fuller account of these investigations.

[1] "Description *vs.* Statement of Meaning," *Am. J. of Psychol.*, 1912, XXIII., p. 182.

THE SHORTEST PERCEPTIBLE TIME-INTERVAL BETWEEN TWO FLASHES OF LIGHT[1]

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The determination of the minimal perceptible time-interval: the shortest interval between two stimuli which allows the stimuli to be perceived as successive, and not simultaneous is important for many lines of work, including problems of time-perception and rhythm and also problems of rate-perception. Moreover an important theory of psychic synthesis has been supported by interpretations of certain measurements of the time-threshold for disparate stimulations (*i. e.*, stimulations of two modes of sense in succession).

My interest in these several lines of research, and also in certain purely visual phenomena, led me to commence, in the summer of 1912, an investigation of the time-threshold for visual stimulation, and its relation to the 'critical frequency' of flicker and fusion. The result of that summer's work (done at the Johns Hopkins University, with myself as principal observer), encouraged me to attempt further work on the problem with better apparatus. During the next college year (1913–1914) a graduate student was allowed to take up the problem, and obtained some results which seemed important.[2] This student, on leaving the University, took his unelaborated results with him, and I have not since been able to obtain them. Last summer, having the opportunity to work in Dr. Hyde's laboratory, I took up the problem again with specially constructed apparatus and obtained results which are interesting and important. I shall give in the following paper the results of both of my experiments.

[1] From the Nela Research Laboratory, National Lamp Works of the General Electric Company.

[2] This work was done with a pendulum apparatus, giving great accuracy, and having other advantages over the rotation apparatus first used; but with some difficulties of manipulation.

The first work on the visual time-threshold was done by Exner,[1] who worked with electric sparks, and found thresholds of 44 σ at 280 mm. distance, and 21 σ at 640 mm. Weyer,[2] in Wundt's laboratory, found a much lower threshold, 12 σ. Weyer also found, using electric sparks, a flicker-threshold from 25 σ to 87 σ, according to the adaptation and other conditions, and a threshold for separation of a series from 42 σ to 105 σ.

Shortly before my work was begun Bassler[3] published the results of some of his investigations, in which he found the time-threshold (length of shortest perceptible dark interval) to be about 40 σ with two visual stimulations, and the flicker point to be about one third as much (for serial stimulation).

None of these results are very significant, the work with electric sparks suffering from lack of control, and Bassler's being affected by serious defects of method.

Bassler used black discs on which were either two white sectors or a regularly spaced series, and rotated the disc close behind a screen in which was a hole a centimeter and a half in diameter. This hole, in which the alternation of black and white occurred, was observed from an unspecified distance. A student in our laboratory reproduced Bassler's apparatus, as nearly as Bassler's description allowed, and we found that eye movement was a very important factor in the observation, the eye movement being induced or increased by the motion of the black and white edges as they traveled across the aperture.

Preliminary Work[4]

It is obvious that the proper attack on the problem of the visual time-threshold involves control of the intensity and the duration of the flashes of light, and of the adaptation and movement of the eye, as well as of the areas stimulated.

In my first experiment I succeeded in eliminating the most

[1] Exner, *Pflüger's Archiv*, XI., S. 407.

[2] Weyer, *Philos. Studien*, XV., S. 67–138.

[3] Bassler, *Pflüger's Archiv*, 1911, Bd. 43, 245–251.

[4] This work was reported before the Natural Academy of Sciences, November 19, 1913. See abstract in *Science*, 1913, Vol. 38, p. 699.

serious important cause of eye movement, namely the traveling of the illumination across the area of stimulation, and kept the illumination constant and the eye dark-adapted. The first factor which I wished to investigate was the effect of the duration of the flashes, and the second was the effect of the intensity.

For simplicity's sake I adopted the method of rotating sectors, measuring the time interval by determining the speed of rotation, and computing from the angular width of the sectors. This method has two serious disadvantages: first, the change in speed, which is necessary to vary the length of the interval between flashes, varies the length of the flashes also, so that the effect of absolute flash length cannot be easily determined, relative length only being controllable. Second, the pair of flashes is necessarily repeated rapidly again and again unless some special device is used to cut off the exposure on all but one round of the disc; and this repetition is a factor which adds greatly to the difficulty of the determination.

My apparatus consisted of a Nernst glower, enclosed in a metal box, with a lens; a disc of white plaster of paris; a motor of controllable rate, driving, by a reducing belt, a spindle on which discs of adjustable sectors could be rotated; and an Ewald chronoscope for counting the rotations of the spindle during a given time.

The lens, 83 cm. from the Nernst glower, focused the light into an image, of approximately the same size as the glower, in the plane of the surface of the rotating sectors on the spindle, with the long axis of the image in a radius of rotation. When not interrupted by the sectors, the light fell on the plaster surface placed 35 cm. beyond the focus, forming a nearly rectangular spot 3.5 by 5 cm. The brightness of this spot was not measured, but was kept constant by maintaining a constant current through the Nernst glower, and by frequently inserting a Lümmer-Brodhun photometer in the position of the disc, comparing the illumination of the Nernst with that of a standardized 8 c.p. carbon lamp. The two brightnesses used were equal to those produced on the same

surface by the 8 c.p. lamp at 36.5 cm. and 67.5 cm.[1] respectively. Since the rotating sectors moved across the beam of light at the focus, 'traveling' of the illuminated areas was nearly eliminated; since the focused image was narrow, the time between the beginning of the illumination (or the dark period) and the full illumination (or complete cut-off) was so small as to be negligible.

The observer (myself in most cases) sat between 75 and 80 cm. from the plaster surface, the angle between his line of sight and the axis of the Nernst beam being 45 degrees. The plane of the plaster surface was so placed that it made equal angles with the axis of the beam and the line of sight.

With this apparatus I made determinations both of the time-threshold for two flashes, and of the critical frequency for a series of interruptions. In the flicker work, a different disc, with the appropriate sectors cut out, was used for each of the different ratios of light to dark interval. In the work on time-threshold, a combination of sectors was used, giving two openings, from 0° to 90° in width, separated by a 5° sector or by a 10° sector. The lengths of flash used with the 5° interval were 5°, 10°, and by 10° steps to 90°: with the 10° interval, flashes of 2.5°, 5° and 10° were used, also several greater lengths, up to 180° for one flash, the other being shorter. The flicker discs (fifteen in number) had each two apertures, with ratios of open to closed ranging between 1/35 to 35/1.

In working on myself the method was as follows: starting with a speed of rotation such that distinct doubleness (or flicker) was observable, the speed was increased by small steps until a single flash (or fusion) was obtained. Then, by depressing a key a circuit was completed through the Ewald, and a circuit-breaker on the spindle, and was allowed to continue for ten seconds: thus the number of rotations in ten seconds was registered. After recording the speed, it was increased somewhat (the amount of increase at this point being purposely irregular), and then decreased by small steps

[1] That is, in the first case, the lamp at 36 cm. gave a brightness clearly brighter than that of the Nernst beam, and at 37 cm. a brightness clearly less.

until the point of doubleness (or flicker) was reached, when the speed was again measured. Three determinations were usually made on each setting of the sectors (or each flicker-disc), before proceeding to the next. The longer series of settings, or series of discs, was gone through with in this way from one to two hours, and as one such series a day was all an observer could endure, the progress of the experiment was necessarily slow.

The observer was instructed to make his judgment each time rather quickly, and then look away until the speed was changed. Continued gazing at the lighted area was found to cause even a pronounced doubleness or flicker to disappear.[1]

The observations were made with darkness adaptation. In working on myself, I took the speed readings, and made the record, by a very dim light, and then waited for a minute or so for readaptation. This procedure undoubtedly had some effect on the determinations, but this effect was probably not large.

The series of settings in the groups were taken in different orders on different days, the several orders being carefully

TABLE I

FLICKER AND FUSION

Observer Dunlap

Sectors in Degrees		Cycles per Second				Durations in Sigmas			
						Flicker		Fusion	
Closed	Open	Flicker	M.V. %	Fusion	M.V. %	Closed	Open	Closed	Open
5	175	24.12	5.86	28.17	5.93	1.15	40.29	0.98	34.48
10	170	28.11	4.20	31.9	4.48	1.97	33.59	1.73	29.53
15	165	31.08	5.51	36.00	5.25	2.68	29.49	2.31	25.45
30	150	38.56	5.16	42.59	5.62	4.32	21.60	3.91	19.56
45	135	42.59	3.51	46.25	4.15	5.86	17.60	5.40	16.21
60	120	43.84	3.55	47.94	4.69	7.60	15.20	6.95	13.90
75	105	44.68	4.00	49.46	4.38	9.32	13.05	8.42	11.79
90	90	45.32	3.07	49.47	4.34	11.03	11.03	10.10	10.10
105	75	45.64	4.07	50.22	4.60	12.00	9.12	11.61	8.29
120	60	44.81	3.70	49.75	4.94	14.87	7.43	13.39	6.69
135	45	44.58	4.23	49.00	4.13	16.82	5.60	15.30	5.10
150	30	41.58	4.72	46.73	3.38	20.03	4.00	17.83	3.56
165	15	38.72	4.57	42.92	5.65	23.66	2.15	21.35	1.94
170	10	35.66	5.39	39.80	4.98	25.48	1.55	23.72	1.39
175	5	29.61	6.42	34.04	6.06	32.82	0.93	28.55	0.81

[1] This 'flicker adaptation' is not due to brightness adaptation, as later work shows.

Table II

TIME THRESHOLD. STANDARD BRIGHTNESS

Observer Dunlap

1. $A = C,\ B = 5.$

$A^\circ = C^\circ$	Double			Single		
	$B\sigma$	M.V.%	$A = C\sigma$	$B\sigma$	M.V.%	$A = C\sigma$
5	19.8	8.0	19.8	13.8	12.3	13.8
10	14.9	10.7	29.8	11.1	9.9	22.2
20	10.5	7.9	42.3	8.2	7.9	32.8
30	7.3	14.7	43.8	6.2	9.1	37.3
40	6.3	13.5	50.9	5.2	10.7	41.7
50	5.4	11.8	54.6	4.5	13.3	4.59
60	4.8	10.1	58.5	4.1	11.2	50.0
70	4.4	10.7	62.3	3.7	6.3	52.9
80	4.3	9.4	69.6	3.7	7.4	60.4
90	4.0	8.4	72.9	3.5	9.9	63.5

2. $A = C,\ B = 10.$

$A^\circ = C^\circ$	$B\sigma$	M.V.%	$A\sigma$	$B\sigma$	M.V.%	$A\sigma$
2.5	28.1	17.8	7.0	20.9	16.5	5.2
5	27.0	11.6	13.5	19.2	13.8	9.6
10	20.6	8.7	20.6	15.9	11.7	15.9

3. $B = 5,\ C = 5.$

A°	$B\sigma$	M.V.%	$A\sigma$	$B\sigma$	M.V.%	$A\sigma$
10	16.0	11.5	33.1	11.9	6.2	23.8
30	11.8	5.7	71.1	9.4	9.1	56.7
50	8.8	8.1	88.3	7.0	4.6	70.8
70	6.6	7.2	92.5	5.6	8.6	78.9
90	5.3	7.8	96.1	4.6	8.1	84.4

4. $A = 10,\ B = 10.$

C°	$B\sigma$	M.V.%	$C\sigma$	$B\sigma$	M.V.%	$C\sigma$
20	20.8	10.6	41.7	16.3	7.8	32.6
60	22.2	18.4	133.5	16.8	9.2	117.7
100	24.3	8.9	243.6	18.1	7.5	181.3
140	23.9	11.3	335.2	18.0	8.9	252.5
180	21.9	7.5	393.3	15.6	13.9	280.8

planned to distribute the effects of practice over the whole series.

The results of my observations are presented in Tables I., II. and III. In Table I. the average flicker-points and fusion-points for the several ratios of open to closed sectors are given both in cycles per second (*i. e.*, the number of complete changes from dark to light and back to light again in a second); and also in the duration in thousandths of a second, of the individual light and dark periods.

In Tables II. and III. the average durations are given for 'A' (the first flash), 'B' (the dark intermediate interval) and 'C' (the second flash) when the flashes appeared discontinuous ('double'), and when they appeared as one uniform flash ('single'). Table II. gives results of work with the higher brightness described above; Table III., with the lower brightness.

Table III

Time Thresholds, Low Brightness

Observer Dunlap

$A = C,\ B = 5.$

$A^\circ = C^\circ$	$B\sigma$	M.V.%	$A = C\sigma$	$B\sigma$	M.V.%	$A = C\sigma$
5	20.5	10.7	20.5	12.4	9.42	12.4
30	8.9	7.6	53.9	7.2	5.6	43.3
70	4.5	7.8	63.1	4.0	4.8	56.8

Table IV

Time Thresholds: Low Brightness

Observer G. R. Wells

1. $A = C,\ B = 5$

$A^\circ = C^\circ$	Double			Single		
	$B\sigma$	M. V.%	$A = C\sigma$	$B\sigma$	M. V.%	$A = C\sigma$
10	19.9	11.0	39.9	13.9	5.7	27.9
30	10.5	9.3	63.1	8.1	10.3	49.1
50	7.1	10.0	71.7	5.5	10.7	55.6

2. $C = 10,\ B = 5$

A°	$B\sigma$	M. V.%	$A\sigma$	$B\sigma$	M. V.%	$A\sigma$
30	13.1	11.8	78.9	9.9	9.2	59.5
50	11.2	9.0	112.4	8.0	8.6	80.7

3. $A = 10,\ B = 5$

30	18.8	10.7	113.3	14.9	8.6	89.6
50	19.5	6.3	195.6	15.0	9.7	150.1

In Tables IV. and V. the results of observations of two other persons are given. These observations were made after I had finished mine, and it was not deemed necessary to use all the flash-lengths which I had observed. In these cases I manipulated the apparatus and recorded the measurements, so that the observers worked under better conditions

Table V

Time Thresholds

Observer H. M. Johnson.

1. Standard Brightness

$A° = C°$	Double			Single		
	$B\sigma$	M. V. %	$A = C\sigma$	$B\sigma$	M. V. %	$A = C\sigma$
5	16.6	14.2	16.6	12.1	9.3	12.1
10	9.4	12.1	18.8	7.8	12.2	15.6
30	7.0	10.0	42.2	5.8	8.9	34.8
50	5.2	8.0	52.4	4.3	4.8	43.4
70	4.5	8.6	63.1	3.8	9.1	54.5
2. Lower Brightness						
5	13.2	7.1	13.2	10.3	5.7	10.3
30	7.0	13.1	42.0	5.8	9.2	35.2

than those under which I observed, specifically as regards adaptation.

Each of the values given in Tables I., II., III. and V. are averages of twenty-five thresholds. The values in Table IV. are averages of twenty thresholds.

There are two points of importance which stand out in these data. First, the rise in rate of the 'critical frequency' (flicker and fusion points) from the extreme inequality to equality of open and closed sectors, in both directions (Table II.). Second, the decrease of the time threshold with increase in the length of the first flash (Tables II., IV. and V.). This decrease seems to be altogether a function of the first flash; increasing the length of the first flash with the second flash constant (II., 3; IV., 2) has almost the effect of increasing both flashes; while increasing the length of the second flash (II., 4; IV., 3) alone has practically no effect. The slight increase in the threshold in both these cases is due to the increased difficulty of observation with the unequal length and hence unequal appearing brightness of the flashes.

In addition to these points, it is to be noted that the time thresholds are low, ranging (with equal flashes) from 4 to 20 sigmas. The comparison of these figures with those obtained in other experiments is, however, not now significant, since we have not as yet analyzed the various factors entering into

determinations of this sort. In addition to the brightness, in regard to which the above data are not significant, the factor of adaptation is probably extremely potent. These results were obtained with fairly good darkness adaptation; they cannot be compared with results obtained with daylight adaptation.

Among the factors affecting the formation of judgments, the rapid repetition of the pair of flashes was conspicuously disturbing. The simple rotation apparatus is not suited to determinations of this kind.

Work on Brightness and Adaptation

The second set of experiments I varried on, at Dr. Hyde's invitation, in the Nela Research Laboratory during the summer months of 1914. In carrying out these experiments I received much help from the staff of the laboratory, and I am especially indebted to Dr. Hyde, the director of the laboratory; to Mr. Cady, assistant director; to Dr. Lorenz; to Dr. Cobb; and to Dr. Johnson. The readiness of the members of the staff to give their time to my problems, and to release to me apparatus from their own experiments, made possible such work as I was able to accomplish in the short time I was there. The greatest burden of the observations fell on Mr. Eric Martienssen, to whom I am indebted for his careful and willing work, under conditions which were sometimes trying.

My apparatus, which need not be described in detail, consisted of the following units.

(*a*) A double rotator,[1] carrying on one axis of rotation two arbors; one on the main shaft and the other on a sleeve on that shaft, the sleeve being geared to an auxiliary shaft and that back to the main shaft, so that the sleeve made one rotation for nine of the shaft. The arbor on the sleeve carried a large metal disc with a 40-degree aperture. Variable cardboard sectors were carried by the faster moving arbor. When the axis of light is parallel to the shaft of this apparatus,

[1] This piece of apparatus was made under my direction in the Physics workshop of The Johns Hopkins University.

whatever exposures are arranged through sectors on the faster arbor are repeated every ninth revolution of the shaft, being cut out the remainder of the time by the slow moving disc.

The main shaft carried also a loose gear, in mesh with a gear on the driving motor; with an electro-magnetic clutch of my devising, so that the disc and sectors could be stopped for adjustment without stopping the driving motor; and could be started again without jerk by turning the current gradually on the clutch magnet. The same shaft also carried a cylinder of brass and hard rubber, on which rested two brass brushes, so that the rotations could be counted by a step-up mechanism operated by the make-and-break of the circuit.

(*b*) A nitrogen-filled lamp, with the wire in a straight compact coil; operated in these experiments at 85, 120, 200 289 and 400 watts. The image of the coiled wire was focused, by suitable lenses, on a slit, to cut off light reflected from the surface of the lamp bulb; and by other lenses refocused in the plane of the sectors carried on the faster moving arbor of the rotation apparatus described above. The axis of the beam of light was parallel to the shaft of the rotation apparatus, and the long axis of the image was radial to the shaft.

The lamp, the slit and the lenses were enclosed in a large hood of black felt drawn over a wooden framework, with an aperture just large enough for the convergent beam to emerge.

(*c*) A movable screen located just beyond the slow-moving disc of the rotator and operated by a hand lever. By raising this screen shortly before the disc made an exposure, and lowering it shortly afterwards, a single exposure of the interval arranged through the sectors was allowed. The manipulation of this screen required no accurate timing, since the slow disc allowed exposure every ninth rotation of the sectors only.

(*d*) A lens, just beyond the hand screen, decreased the divergence of the cone of light, increasing the brightness of the surface illuminated.

(*e*) A plaster disc, surfaced with magnesia, illuminated by the cone of light. This disc was 12.5 cm. in diameter, and

about half the diameter of the light cone at the point of insertion of the disc and had a background of black velvet upon which the light around the disc was negligible. The plane of the disc was vertical, but was at an angle of 30° from the plane perpendicular to the axis of the cone of light.

The observer sat so that his binocular line of sight was perpendicular to the disc, which was about 165 cm. from his eyes.

(*f*) A miniature projection lamp, with a small incandescent bulb entirely enclosed, established out of the range of the observer's vision, cast on the object disc a group of four small dots, which served excellently as a fixation mark.

(*g*) Eight mazda lamps, totalling 600 watts, so disposed in the room that the walls were illuminated, especially the wall in front of the observer—the wall behind the plaster disc—but the lamps were screened from the observer's eyes. These lamps were controlled by a single switch.

(*h*) A single mazda lamp in a long black cardboard tunnel, arranged to throw continuous illumination, when desired, on the disc.

(*i*) An Ewald chronoscope, for counting the rotations of the sectors, as a control of the accuracy.

(*j*) A synchronous motor[1] for driving the rotator. This had eight poles, and working on 60 cycle A.C. current gave 15 rotations per second. This motor was geared to the main shaft of the rotator (*a*), the ratio to the gear on the motor shaft being 1 to 3. The main shaft therefore made five rotations per second, so that for the sectors carried by the arbor on the main shaft 9° equalled 5 σ. The variations in speed, due to variations in current frequency, were negligible during the periods of work.

(*k*) A small D.C. motor for starting the synchronous motor. This starting motor was belted to a one-flanged pulley on the shaft of the synchronous motor so that the belt could be thrown off when the synchronous motor was working properly. A stroboscope disc mounted on the same shaft, and illuminated by a 15-watt lamp on the A.C. current,

[1] This motor was one which Dr. Lorenz had constructed for his use. The stroboscopic method of starting the motor was also suggested by him.

indicates the proper moment for turning on the synchronous motor.

The five wattages used on the lamp gave brightnesses on the object disc of 3, 10, 36, 82 and 168 candles per square meter. This range of illuminations seemed adequate for the investigation of the effects of brightness, which was the first point I had planned to attack.

The results of the preliminary experiment, reported above, had shown clearly that the threshold for doubleness (measured in terms of the dark interval) depends on the length of the flashes, especially of the first flash, although the absolute magnitudes of the thresholds as determined in those experiments could not be supposed to be very significant. It would therefore be possible, theoretically, to determine thresholds in either of two ways: first, by keeping the dark interval constant and varying the flashes; and second, by keeping the flashes constant and varying the dark interval. It would seem equally useful to work out the thresholds in flash length for several fixed dark-interval lengths, and to work out the thresholds in dark-interval length for several fixed flash-lengths. In either case the effect of the brightness, and of adaptation could (it would seem) be worked out in an adequate way.

In the manipulation of apparatus, the first procedure is far the simpler. The sector adjustments are not so complicated, and hence the progress of the experiment should be more rapid. Realizing that the work would at best be slow, I chose the plan which offered this important advantage.

Observations were made at first with dark adaptation exclusively. The subject was kept in the room from ten to twenty minutes before commencing work, according as he had come in from outdoors, or from more or less dimly lighted work rooms. No warning signal other than the normal sound of the electro-magnetic clutch in taking hold, was needed by the observer. The motor ran continuously, and the clutch was thrown in when an observation was desired. The rotator 'picked up' full speed in less than a second; the hand screen was lifted about two seconds after

the clutch was thrown in. The four dots of light in the center of the disc fixed the line of sight before the flashes occurred. Four repetitions of the exposure were given in succession, but the observer usually gave his judgment after the second or third.

Observations were carried on for some time by Martienssen and myself by this method, using the procedure of 'serial groups,' but the results, although interesting, were of little value for the purposes of the experiment. Variations in the durations of the flashes produced variations in the apparent brightness and apparent color of the disc, which were at first extremely confusing, and on which finally the judgments came to depend, rather than on any real appearance of 'doubleness' or 'singleness.' One set of five hundred judgments by Martienssen, which are typical, are given in Table VI.

TABLE VI

Martienssen

Dark interval 25σ. Brightness 82 c. per sq. m.

Two Flashes	Double	Single	One Flash	Double	Single
70σ	48	2	140σ	0	50
60	36	14	120	0	50
60	38	12	100	3	47
40	32	18	80	11	39
30	41	9	60	12	38

In this table the first column gives the length of flash where two were used, the second and third columns giving the number of judgments of double and single for each flash-duration. The fourth column gives the durations of the single flashes, each equal to the sums of the two in the corresponding pair; the fifth and sixth columns giving the number of judgments of single and double respectively for each of these single flash durations.

The increasing difficulty of discrimination is here shown, not so much by the increased tendency to call the double flashes single, as by the tendency to call the single flashes double. Obviously, no definite threshold can be determined

when this tendency is present.[1] This tendency, it must be noted, is not due to mere confusion; as we shall see later, a single flash often appears distinctly double, and with the same sort of doubleness as is noticed in a really double flash. In this particular set of observations, however, the judgments, according to the observer's report, were based largely on differences in apparent brightness and color; at least this seemed to him to be the case in the latter part of the set.

Table VII

Martienssen

Dark interval 25σ. Brightness, 3 c. per sq. m.

Two Flashes	Double	Single	One Flash	Double	Single
50σ	26	4	106σ	3	23
50	16	4	80	4	16
30	18	2	60	2	18
20	15	5	40	4	16
10	15	5	20	11	9

The results of a set of observations by Martienssen with lower brightness are given in Table VII. Results of a set of observations by Dr. Johnson on the moderate brightness are given in Table VIII. Other sets with different brightnesss gave results of the same order.

Table VIII

Johnson

Dark interval 25σ. Brightness, 82 c. per sq. m.

Two Flashes	Double	Single	One Flash	Double	Single
50σ	20	0	100σ	1	19
40	17	3	80	7	13
30	23	7	60	4	26
20	10	10	40	5	15

In this set of observations, the observer's judgment was influenced very largely by the apparent duration of the total

[1] This condition is similar to that found in attempting to determine the 'two point' threshold by simultaneous stimulation of the skin. No threshold can be determined, since *one* stimulation frequently is perceived as two, and hence the least separation of two points giving a certain percentage of perception of two has no definite significance.

exposure; the greater duration of the two flashes was noticed, especially with the shorter flash-lengths, and this tended more and more to become the criterion of doubleness.

The procedure by groups ('method of serial groups'), it was clear, could not be used in this experiment. The secondary criteria—in this case the differences in brightness, color, and duration—are made maximally conspicuous by this method, and judgments strictly on the points under examination are made practically impossible. I therefore attempted to use the shuffled series procedure, still clinging to the method of constant dark interval. A few series, however, showed that this method was not practicable, even when the better procedure was employed, since the differences in brightnesses and color still were very conspicuous. The regular progression procedure ('method of minimal change') accentuated these secondary criteria still more.

The effects of the total duration had been foreseen, and I had expected to introduce variations in which the single flash should be equal in length to the two flashes *plus* the dark interval. This variation was found to be inapplicable because it would have accentuated the brightness differences. For example; the greater brightness of the 100 σ flash as compared with the two successive flashes of 50 σ with 25 σ dark interval, would be still greater if the lengths of the two flashes were reduced to 37.5 σ each.

The next attempts were made by the method of constant flash-length, using the 'shuffled series' procedure. With this method the differences in apparent brightness are not so marked as with the constant dark-interval method, and by this procedure these differences and the differences in duration are not so disturbing as they are in the serial group procedure. It is possible, in other words, to form judgments on the apparent doubleness or singleness alone of the flashes, although it required a high degree of training in order to eliminate absolutely other criteria.

The results of these next observations by the shuffled series procedure are given in Tables IX., X., XI. and XII. In these tables the first column gives the separation of the

two flashes, and the other columns give the number of judgments of 'single' and 'double' for each of the five brightnesses. The observations with all of the brightnesses were obtained on the same days, a series being taken with each brightness during each experimental period, the order of brightness being altered from day to day in a regular way.

TABLE IX

Martienssen

Flash = 50σ

Intervals, σ	Brightnesses, Candles per Sq. Meter									
	3		10		36		82		168	
	d.	s.	d.	s.	d.	s.	d.	s.	d.	s.
0	11	13	5	15	9	15	11	9	5	19
5	8	4	5	5	9	3	5	5	7	5
10	6	6	7	3	5	7	7	3	8	4
15	9	3	5	5	9	3	6	4	9	3
20	10	2	4	6	11	1	8	2	6	6
25	11	1	8	2	10	2	10	0	8	4

TABLE X

Johnson

Flash = 50σ

Intervals, σ	Brightnesses, Candles per Sq. Meter					
	3		10		168	
	d.	s.	d.	s.	d.	s.
0	4	16	0	20	0	20
5	5	5	0	10	2	8
10	7	3	2	8	3	7
15	8	2	4	6	8	2
20	10	0	9	1	9	1
25	10	0	8	2	10	0

Other series were taken with light adaptation. In this work the room was lighted by the mazda lamps referred to under (*g*), and the observer was adapted to the brightness of the plastered wall due to this illumination. When ready to make the observation, the lights were switched off, approximately 1.5 seconds before the exposure of the flashes (or flash). This interval was timed by watching the exposure on the hand-screen; and turning off the lights immediately

after such exposure. Then the hand-screen was lifted, and since the exposure occurred every 1.8 seconds (the rotation-period of the slow moving disc) the interval between the turning off of the mazda lamps and the exposure on the object disc was timed sufficiently well.

TABLE XI

Martienssen

Light Adaptation. Flash = 50σ

Intervals, σ	Brightnesses, Candles per Sq. Meter					
	3		36		168	
	d.	s.	d.	s.	d.	s.
0	5	25	6	24	3	27
5	2	17	12	13	6	14
10	15	6	15	5	14	16
15	17	2	18	2	19	1

TABLE XII

Johnson

Light Adaptation. Flash = 50σ

Intervals, σ	Brightnesses, Candles per Sq. Meter					
	3		36		168	
	d.	s.	d.	s.	d.	s.
0	0	25	2	23	5	20
5	5	15	12	13	9	11
10	13	6	10	10	18	2
15	24	1	16	3	19	1

This method of working with light adaptation seems quite satisfactory. An interval must be allowed between the turning off of the adaptation light and the beginning of the stimulus light, to allow muscular recovery. The one-and-a-half second period seemed to be about the shortest which could be used. Of course a slight amount of adaptation occurs within this period, but this is kept constant throughout.

Series with darkness adaptation followed the work with light adaptation. Results of one group of series on Martienssen are given in Table XIII. The remainder of the

work on this observer and on Dr. Johnson was directed to 'feeling out' methods, and does not lend itself to tabulation.

TABLE XIII

Martienssen

Dark Adaptation. Flash = 25 σ

Intervals, σ	Brightness, Candles per Sq. Meter					
	3		36		168	
	d.	s.	d.	s.	d.	s.
0	7	7	3	11	1	13
15	9	5	9	5	9	5
20	13	1	13	1	8	6
25	14	0	14	0	11	3

From the results, as tabulated, little can be inferred as to the effect of brightness. It is evident that adaptation is an important factor. The factor of greatest consequence, however, is the tendency to see the single flash as double. The effects of this tendency are found in the tabulated results, especially with the lowest brightness, and were still more evident in the work not tabulated.[1] Attempts to use flashes longer than 50 σ proved fruitless on account of this tendency. At 75 σ, for example, there was a large increase in the number of 'double' judgments on single stimuli. There is a limit, however, beyond which the double appearance is not found. It may be useful, later, to determine both the upper limit and the lower limit for the fallacious doubling, but this is a determination of the most difficult sort.

The double appearance of the single flash may, with practice, be distinguished from the true 'doubleness.' That is, there are times when the 'doubleness' of a single flash is clearly different from the 'doubleness' of two successive flashes, if the one and the two are shown with but little pause between. This discrimination is apt to be lost at any time, however, and the pseudo-'doubleness' taken for real 'doubleness.'

As an illustration of the discrimination, the following observation of Dr. Johnson will serve.

[1] In many cases, both with one flash and with two flashes, the appearance was 'double' on first exposure and 'single' on the succeeding exposures.

1. With the brightness = 36 (c. per sq. meter), two 40 σ flashes were distinguished from one 80 σ flash when the interval was 20 σ; with 15 σ interval, the one flash and the two flashes looked *equally double.*

With brightness = 3, the two were distinguished from the one with 15 σ interval.

With brightness = 168, discrimination was clear at 25 σ; not at 20 σ.

2. With two 25 σ flashes, and one 50 σ flash, the difference was clear when the interval was 35 σ, with all the brightnesses, equal 'doubleness' at 30 σ.

3. With two 10 σ and one 20 σ flashes, the discrimination was clear when the interval was 55 σ for the 3 and 36 brightnesses, and 40 σ for the 168 brightness. Below these points the 'doubleness' was the same.

Similar observations by Dr. Cobb gave the following results:

1. Two 25 σ flashes and one 50 σ flash, with brightness = 3, 'doubleness' clear at 40 σ interval. With brightness 36 and 168, 'doubleness' clear at 30 σ interval.

2. Two 50 σ flashes and one 100 σ flash, with brightness = 3, clear at 20 σ.

With brightness = 36, clear at 25 σ.

With brightness = 168, clear at 30 σ.

3. Two 10 σ flashes and one 20 σ flash, with 3 and 36 brightnesses, not clear below 50 σ (no longer interval used): with 168, clear at 45 σ.

4. Two 75 σ flashes and one 150 σ flash, brightness = 3, clear at 10 σ interval. Brightness = 36 and 168, clear at 15 σ interval.

On the whole we cannot conclude that increasing the brightness of the flashes increases the distinction of the doubleness of two. This is a matter that is dependent upon the absolute length of the flashes. In subsequent work, carried out on the two observers listed above, and on Dr. George R. Wells, the effect of brightness was brought out directly by trying various intervals in succession with the same flash-lengths. This work, while agreeing with that

reported above, brought out the further fact that the effect of intensity variations on successive flashes which are hardly distinguished at best because of the shortness of the interval, is not the same as the effect on succession with longer intervals.

These observations are not consistent with the tabulated results, but there is no reason why we should expect them to be so, since the conditions of observation were entirely different. We must always distinguish in problems of this kind variations in the actual observable phenomena established by the experimental conditions, and the variations in the observations of these phenomena which may be due to the same conditions. For example: the sensible content from two (successive) stimulations may be different from the sensible content due to a single stimulation, and yet on account of the circumstances of observation, the difference may not be noted. On the other hand, a sensible content of a certain sort may now be judged like, now be judged different from, a content from which it differs slightly, according as the conditions of observation throw this difference in relief, or minimize it.

My Own Observations

During the course of the experiments reported above, I acquired a considerable facility in observation, since I watched the flashes while having full knowledge of the stimulus conditions. I did not record my observations during the work with the other observers, since the necessity of conducting the experiments for them, and especially the attention to speed and accuracy in the adjustment between exposures, was a disturbing factor.

Later I made observations (with knowledge) myself under satisfactory conditions. In these cases I worked with the 'progressive procedure,' starting alternately with a setting (width of dark interval) giving *no doubleness*, and one giving *doubleness*.

This work was done at night, and the results on different nights did not agree absolutely. There was, however, a

general uniformity, such as is indicated in Table XIV., in which are given the results on four nights during August. The figures given are not averages, but absolute values in the scale of 5 σ steps; the points at which (and above which) the flashes were always seen 'double' (d.) and at which and below which they were seen 'single' (s.) on that night under

TABLE XIV

Dunlap

Flash = 50 σ

1. Aug. 4

Brightness	Dark Adap.		Light Adap.		Constant Light	
	d.	s.	d.	s.	d.	s.
10	40	30	20	5	20	5
36	40–50	30	20	5	20	5
82	40–50	30	20	5	20	5
168	40	30	10–30	5	20	5

2. Aug. 22.

Brightness	Dark Adap.		Light Adap.	
	d.	s.	d.	s.
3	25	15	20	10
10	25	15	15	5
36	25	15	5	?
82	25	15	5	?
168	25	15	10	5

3. Aug. 23

Brightness	Dark Adap.		Light Adap.		Constant Light	
	d.	s.	d.	s.	d.	s.
3	20	10	20	5–10	5	2.5
10	20	10	10	?	5	2.5
36	20	5–10	5	?	10	5
82	20	15	5	?	10	5
168	20	10–15	5	?	10	5

the conditions indicated. When the threshold varied during the test, the variation is indicated. The observation lasted from one to two hours, with periods of rest for the eyes.

In certain cases, no definite determination was made for the 'single' point. This is indicated by a question mark.

The series with dark adaptation and light adaptation were taken as in the work on other observers. The results in the columns under 'constant light' were obtained while the object disc was illuminated by the 'tunnel lamp' described above, (*h*). In this case, the flashes were superimposed on a constantly lighted surface. Except for the illumination of the disc, the room was dark during these observations.

The observations included in Table XIV. were with 50 σ flashes only; with 25 σ the results were more uniform; for all brightnesses, with dark adaptation, the double point was at 40 σ, the single, at 30 σ; with light adaptation, the points were 20 σ and 10 σ respectively; with light adaptation and constant light in the disc, 20 σ and 5 σ. With dark adaptation and constant illumination, the single point was 5 σ, but the double point was variable (10 σ–20 σ). Flashes above 50 σ (up to 75 σ) gave more variable results.

The general influence of light adaptation and constant illumination was demonstrated on a number of persons, including the observers listed above, by a simple method. The sectors were set so that with dark adaptation the two flashes appeared 'single,' or the judgment was 'doubtful.' Then the eye was light-adapted for a short time, and observation showed a striking change, it being possible with any observer to change the judgment from 'distinctly single' to 'distinctly double' by this means. The addition of a constant illumination served the same purpose. With certain settings of the sectors, and a faint constant illumination on the disc, the two flashes appeared 'single'; by increasing the constant illumination a point was reached at which the appearance was clearly double. This point varied with different observers, and at different times.

The Sources of Difficulty

The results of the investigations of the visual time threshold up to this point are as follows:

1. The effects of *brightness* of the light are variable, depending on the other factors in such a way that no conclusion can be drawn as yet concerning their effects.

2. The threshold is lower for the light-adapted eye than for the dark-adapted eye. This holds, at least, for certain light-adaptations.

3. The threshold is lower for an interval marked by flashes added to a continuous stimulation, than flashes in a dark field. This holds for a wide range of constant illumin-tion, the threshold varying usually with the brightness of the constant illumination up to the point where the additions lose in distinctness.

4. A single flash is frequently seen as a succession of two, and although this 'twoness' may, under proper conditions, be discriminable from actual 'twoness,' these conditions are not easily actualized in quantitative work.

In consequence of this (and, possibly, other factors) quantitative work by the standard methods is not possible; at least the results of such work are unreliable. Special methods must be devised.

5. It is impossible to train observers on the light threshold problem in a limited time (two or three months). Observations are of value only if made by persons having a long training in that particular work. In this respect, the time-threshold problem differs markedly from certain other problems, *e. g.*, of flicker. The length of training required cannot be specified, but possibly should extend over a period longer than a year.

The most interesting question coming out of these observations concerns the apparent doubleness of a single flash under certain conditions. This doubleness of appearance is unquestionable; the flash has at times a striking 'one-two' progression.

This fictitious doubleness is not exclusively a dark-adaptation phenomenon, although it is less noticeable with light-adaptation. Constant illumination, on the other hand, even of relatively low brightnesses, completely abolishes it. We might therefore suppose it to be due to an iris-reflex: the stimulation beginning with dilated iris causes a strong contraction and immediate relaxation, so that the light-flux entering the eye drops and rises again causing a depression

('dimple') in the excitation curve of the retinal process in the same way as in a rapid succession of two flashes.

The occurrence of the flash provokes a strong visual reflex, noticed by every observer. One feature of this reflex is an increase in accommodation: at the end of the stimulation, this accommodation is for a point nearer than the object-disc, and the relaxation necessary to re-accommodate for the disc is easily noticed. Since accommodation and iris-contraction go together this may be taken as indicating the iris factor suggested above.

On the other hand, the chief factor may be retinal. The retinal process may rise to a point higher than its 'normal' for the intensity of stimulation, and then drop back.[1] The drop may be below normal, with an immediate second rise; thus the 'dimple' which normally produces the appearance of doubleness may occur independent of iris-activity.

It is possible that no 'dimple' may be required. The two drops in the sensation,—one following the excessive rise, and the other at the end, may be interpreted as 'twoness.'

The motor-process—adjustment of the eyes—may be connected with the fictitious doubleness through an actual inhibitory discharge to the retina accompanying the discharge to the ciliary muscle. Efferent fibers to the retina are known to exist, although their function is not known.

The motor-process is probably the cause, or connected with, the severe effect of the observations. Both Martienssen and myself felt the effect to a marked degree, the eyes becoming very irritable, and necessitating frequent interruptions of the work.

Instead of being towards the end or in the middle of a very simple experiment, or small group of simple experiments, we are now at the place where it is necessary to take up a large number of points, not so clearly connected with each other as they are contributory to the solution of our initial problem. If any light is to be thrown on these problems, it can come

[1] Such action of a light stimulation on the retina is called by physicists the 'over-shooting of the sensation.'

only through the solution of these various problems, each of which involves an extended investigation.

The problem, or group of problems, which stand out above the others in importance, concerns adaptation. I am now installing apparatus and developing methods which may throw new light on this topic.

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